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THE TWIN LAKES GLACIATED AREA, COLORADO[1]

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OUTLINE

PREGLACIAL TOPOGRAPHY OF THE UPPER ARKANSAS.
GLACIAL FEATURES OF THE TWIN LAKES REGION.
I. Morainic System of Lake Glacier.
II. Pleistocene History of the Upper Arkansas.
III. Glacial Erosion.
POSTGLACIAL CHANGES.
MOUNTAIN FORM.

The Upper Arkansas occupies a broad north-and-south valley between the Park Range on the east and the Sawatch Range on the west. Twin Lakes are on the lower course of Lake Creek, which heads in the Sawatch and flows east to the Arkansas. The lakes are held back by two small recessional moraines deposited by the glacier

[1] The writer, on returning from the Harvard excursion to the Great Basin in 1904, spent several weeks in the valley of Lake Creek. Together with Professor W. M. Davis, he had stopped here for a few days earlier in the summer, and he wishes to express his indebtedness to Professor Davis for pointing out the district to his attention as deserving study for its glacial features, and for suggestions in the field and later.

The only early detailed report on the region is found in the *Annual Reports* of the Hayden Survey for 1869, 1873, and 1874. A paper by Capps and Leffingwell, which was published in the *Journal of Geology* for November–December, 1904, discusses the glacial geology of the upper Arkansas valley, and with the conclusions of these writers the author is in substantial agreement, in so far as the two papers deal with the same area. Professor Davis, in *Appalachia*, November, 1904, uses the valley of Lake Creek to illustrate glacial erosion.

which formerly occupied the valley of Lake Creek. This paper describes the topographic features of the basin of Lake Creek and of the neighboring part of the Arkansas valley, and treats of the preglacial topography of the region, the topographic effects produced by Pleistocene glaciation, and postglacial changes.

PREGLACIAL TOPOGRAPHY OF THE UPPER ARKANSAS

All of the larger tributary valleys of the Arkansas on the west, and some of those about Leadville on the east, were occupied by valley glaciers during Pleistocene time, while the other tributary valleys

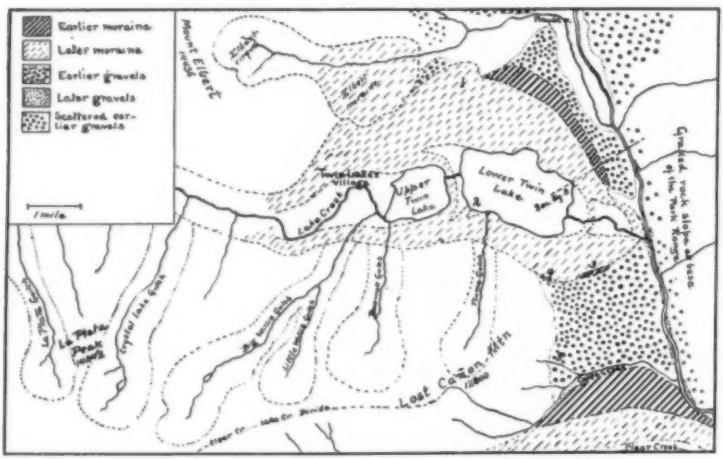

FIG. 1.—Map of the Twin Lakes area.

and the main valley were free of ice. It is thus possible to compare the glaciated and non-glaciated areas, and to determine what features are due to stream-erosion in preglacial time, and to contrast that topography with that which has been changed by glacial action.

Fig. 2 will make clear the main elements of preglacial form along the Arkansas. The river flows in a narrow interglacial valley cut 300 to 400 feet into the granite. From the edge of this inner valley on the east a terrace (*BC*), from one-half to a mile in width, rises at an angle of 5° to the foothills of the Park Range. This terrace is cut in granite, and while now somewhat dissected, is evidently a

part of the graded rock-floor of the preglacial Arkansas. The west wall of the narrow valley is granite, but the plain (*AD*) stretching west from its upper edge is glacial wash, and not cut on the rock. The rock-plain which one naturally looks for to match that on the east is buried under this wash and is shown at only one point along the base of the range, just south of the south Lake Creek moraine, where placer mining has removed the thin cover of gravel over a considerable area, and shows a graded slope of weathered granite inclining to the east, and at the same level as the back of the corresponding rock-slope east of the Arkansas. Placer digging west of Granite, and occasional shafts, show that the gravel is upwards of 50 to 75 feet in thickness; it may be much more. This gravel filling is probably not thick enough to carry the bottom of the broad preglacial valley, which ran west of the present river, down to the present level of the Arkansas. The dotted line in the section restores approximately the surface of the preglacial valley.

FIG. 2.—Section across the Arkansas River north of Granite.
Horizontal and vertical scale, 1 inch =4 miles (nearly).

At its back edge the graded rock-slope passes into the foothills of the Park and Sawatch ranges. The hillsides comprising these ranges are not steep, rarely over 20°, and have graded slopes, without prominent outcropping ledges, and this type of hill form is kept all the way to the summits. These rise some 3,000 to 5,000 feet above the valley, and are rounded and massive. Sharpened summits occur only in the glaciated areas. The Sawatch Range above Granite, Lost Canyon Mountain, and Mount Elbert all show this massive form, which may be taken as the typical preglacial form.

GLACIAL FEATURES OF THE TWIN LAKES REGION

That part of the Lake Glacier (name shortened from Lake Creek Glacier) which lay in the broad valley of the Arkansas was characterized by morainic deposition; that part above Twin Lakes village, and which lay in the narrow valley in the Sawatch, by glacial erosion.

I. MORAINIC SYSTEM OF LAKE GLACIER

1. *Two periods of glaciation.*—The moraines of the Lake Glacier form a rough semi-circle on the west side of the Arkansas, reaching almost to the present Arkansas River.[1] Within this area moraines of two distinct dates are found, separated by a time interval of sufficient length to constitute two separate glacial periods. Their distribution is shown on the accompanying map (Fig. 1). The later drift forms a continuous moraine about the lakes. The earlier drift occurs outside the later drift for four miles north of Lake Creek, and at one or two isolated points south. The evidence for the different age of the two moraines lies (A) in the relations which they hold to the gravels of the Arkansas valley, (B) in the difference in weathering in the two moraines and gravel-plains, and (C) in differences of topographic expression and amount of stream-dissection of the two moraines and their correlated gravels.

A. Relation of moraines to gravels. Two series of gravels occur along the Arkansas. One is a succession of terrace fragments, lying within the interglacial gorge of the Arkansas and rising some 30 to 40 feet above the river. At Lake Creek this terrace rises somewhat steeply to the front of the later moraine, and the relations of the two show clearly that the gravel is a wash-plain formed by the glacial waters contemporaneously with the accumulation of the moraine. The later moraine is therefore of later date than the cutting of the rock-gorge of the Arkansas.

A second series of gravels occurs up to 400 feet above the river-level, back from the upper edge of the rock-gorge, and on both sides of the river. East of the river they form in places a thin veneer over the graded rock-plain of the preglacial Arkansas; in large part, however, they are represented only by scattered bowlders.[2] West of the river they form extensive terraces. That the deposits were originally continuous is shown by their occurrence at the same levels on both

[1] There is no evidence that the Upper Arkansas was ever occupied by a north-and-south master-glacier, as suggested by Hayden, *Annual Report* for 1873, p. 48.

[2] Referred to by Capps and Leffingwell (*Journal of Geology*, Vol. XII, p. 702) as possibly indicating a third period of glaciation earlier than the two to be mentioned later. They seem to be associated, however, with the upper terrace gravels, though floating ice may have had some share in bringing them to their present condition, as they are sometimes 2 to 3 feet in diameter.

sides of the river, and by the fact that the gravel east of the river contains material recognizable as derived from the valley of Lake Creek, and not found east of the Arkansas. Through this sheet of gravel the Arkansas cut its valley, and then 300 to 400 feet into the rock. These higher gravels are therefore older than the rock-valley. But it is with this older series of gravels that the outer moraine is to be correlated. Fig. 3 shows the relations that hold along the whole stretch of the old moraine north of the river. *A* is the later moraine; *B*, the earlier moraine; *C*, the upper gravel-terrace. On the rock-terrace at *D*, scattered bowlders or thin gravel veneer mark the former eastward extension of the terrace. *E* is the gorge gravel of younger date. *C* is the wash-plain to the outer moraine *B*, just as

FIG. 3.—Profile from lower Twin Lake northeast to the Arkansas. Symbols as in Fig. 1.
Horizontal scale, 1 inch=2,000 feet; vertical scale, 1 inch=5,000 feet. The section is located on the map.

the gorge gravels are to the later moraine. These relations of the moraines to the gravels show that the periods of ice-advance indicated by the two moraines are separated from each other by a time interval sufficient for the Arkansas to cut its gorge 300 to 400 feet below the floor of its broad, graded, preglacial valley. When one compares the work done in this period with that done by the river in postglacial time, in which it has not been able completely to clean out of its valley the gravels of the later glacial period, one can get an idea of the relatively long time separating the two periods.

B. Differences in weathering of the two moraines and their associated wash-plains. The great difference in age of the two glacial advances is further shown by the difference in the amount of weathering of their deposits. The later moraine, as seen in cuttings, is everywhere fresh and unweathered. The large stretch of older moraine north of Lake Creek does not show sections which will enable one to make a comparison with the later drift. The western of the two occurrences south of Lake Creek, however, shows a long section where the moraine is crossed by an irrigating flume. The moraine here is thoroughly disintegrated, bowlders crumbling to pieces

beneath the blow of a hammer, while the same rock on the inside of the younger moraine is quite fresh. It may be noted, though, in this connection, that in one or two exceptional cases the younger moraine contains frequent decomposed bowlders.

It is, however, when we come to examine the gravels associated with the two moraines that the difference in amount of weathering is most apparent, and numerous placer openings and trial shafts in the gravels have made this comparison easy. Sections in the gravels in the gorge show that the bowlders are, with very few exceptions, perfectly sound. Numerous sections in the upper gravels show a large proportion of the bowlders to be thoroughly rotten. One of the most easily recognized rocks of the region is a coarse porphyritic granite. In the gorge gravels, bowlders of this rock are fresh. In the upper terraces they can often be picked apart with the knife-blade, and frequently have been cut across in digging the shaft, it being easier to cut across than to dig out blocks lying in the wall of the shaft. This very general and thorough weathering of the upper gravels, compared with the freshness of the gorge gravels, indicates that the former are several times older than the latter, and that interglacial was longer than postglacial time.

C. Differences in topographic expression and in amount of stream-dissection of the two moraines and their associated gravels. In a later place this consideration will be presented more fully. It is enough here to say that the younger moraine is the steeper and more rugged of the two. The differing amount of dissection is especially well brought out in the two gravels. Of course, the gorge gravels have been in large part cleaned out by the Arkansas in postglacial time, since along the main river conditions have favored erosion. More striking is the great amount of destruction of the upper gravels at points where erosion has not been favored. They have been completely cleared away by Lake Creek at its mouth, and by the small stream entering the Arkansas at Hayden. Between these two points no permanent streams enter the Arkansas from the west, but several dry valleys head in the old moraine, cross the wash-plain and enter the main river. Near the river they are in granite and narrow, farther back they are in gravel and widely open. These widely open valleys in the old gravels contrast well with valleys cut

by much larger streams in the younger drift—as, for example, the valley of Lake Creek where it crosses the moraine—and point to the gravels being much older. There is reason to believe that the streams entering the Arkansas from the west between Lake Creek and Clear Creek have, by widening their valleys until they joined, succeeded in reducing the whole level of the upper gravel deposits some distance below its original height. The dry valleys which cross the gravel terrace north of Lake Creek head, as has been mentioned, in the older moraine. Their continuation from the river with essentially unchanged dimensions and expression, back across the gravel terrace into the older moraine, but not into the younger moraine, shows the connection of the older moraine and the higher gravels. The younger moraine is not eroded by any drainage originating on the moraine itself.

The relation of the moraine to the gravels shows that the valley of Lake Creek was at two distinct periods in Pleistocene time occupied by a glacier, and that these two periods were separated by time enough for the cutting of the rock-gorge of the Arkansas. And the much greater weathering and erosion of the older deposits indicate that interglacial time was much longer than postglacial time, in this region.

2. *The earlier moraine.*—The character of the older drift is well shown outside the younger moraine north of Lake Creek. Here, toward the south, it forms a low terrace several hundred feet wide rising some 30 to 50 feet above the wash-plain which fronts it. From a distance it looks almost like a second terrace rising above the general level of the upper terrace, but its surface is rolling and uneven. It is usually separated from the younger moraine by a shallow valley. Its surafce, while rolling, is less uneven and rocky than that of the younger drift; scattered erratics up to 6 or 8 feet in length are common over its surface, but these do not reach the size of those on the other moraine. Northwest, this terrace widens to about a mile, forming a gentle slope away from the later moraine to the wash-plain nearer the river. This older drift has not been traced beyond the Twin Lakes–Hayden road.

The older drift is mapped at two places south of Lake Creek. The western of these two occurrences (Fig. 1, 4) is not large enough

to be of topographic importance. The other (Fig. 1, 3) is a low ridge nearer the river, apparently connected with a fragment of the upper terrace gravels, and less rugged than the younger drift just north of it. It is not in as marked contrast with the younger drift as the belt of older moraine north of Lake Creek, and there might be some doubt as to its identification. No sections occur, so that one kind of evidence as to its age is lacking.

3. *The later moraine.*—The later moraine forms a loop about the lower end of Lake Creek, with its higher parts, near the Sawatch Range, rising some 1,000 feet above Lake Creek. Its surface has already been described as more rugged than that of the older moraine, yet it shows typical kettle topography at but one place, where the Hayden road crosses the north lateral (Fig. 1, 1). The outer slope is the steeper of the two. An interesting feature of the inner slope of the north moraine is a series of ridgings which remain parallel to the main crest of the moraine for some two miles as it drops to the east, and which seem to represent later stages of accumulation during the beginning of the retreat of the glacier.

At several points there are sags in the moraine crest, and here the moraine is pushed forward as if tongues of ice had pushed out a short distance beyond the general front of the glacier. The best illustration of this is at the lower end of Lake Creek, where the main morainic ridge is breached, and a small moraine pushes out through the breach nearly to the Arkansas River. The contrast is especially noticeable on the north, where the two make a sharp angle with each other. A second illustration occurs on the north lateral, where it is crossed by the Hayden road, and again on the south lateral between the two areas of older drift.

Moraines of recession occur along the course of Lake Creek. The first of these is just below the lower lake—a belt of low morainic knolls which swings around and unites with the inner side of the main moraine. This moraine of recession can be traced to its union with the main moraine, but it cannot be separated from the main moraine thereafter. A second low recessional moraine swings in a semi-circle across the valley at Interlaken, separating the two Twin Lakes from each other. This has its wash-plain, and merges with the larger moraine, though it can be followed back as a distinct ridge

for a greater distance than the moraine below the lower lake. A third morainic ridge (Fig. 1, 2), a part of a recessional moraine, is developed on the south side, just down-stream from the one just mentioned at Interlaken. It runs below the level of the lower lake, and is not found on the north side of the lakes. Masses of morainic drift occur within the rock-gorge, but irregularly distributed, rather than in the crescentic shape characteristic of recessional moraines. In all cases these moraines are small, forming a belt of rolling drift 20 to 30 feet high and not exceeding several hundred feet in width.

Above Twin Lakes village, in the rock-gorge of Lake Creek, the drift occurs irregularly and is not aggregated into moraines. Erosion and not deposition was here the rule. From the base of the mountains to the Arkansas the drift occurs in simple morainic embankments. There is an intermediate area, on both north and south sides, where an intermediate relation holds. On the south side of Lake Creek the south lateral rests against the lower slope of Lost Canyon Mountain, its crest dropping slowly to the east and interrupted only where cut by streams flowing into Lake Creek. At these places a typical moraine section is shown, as the moraine was built across the mouths of the lateral valleys which were occupied by streams in their lower course and entered the main valley well below the level of the glacier surface. Opposite the intervening divides the moraine crest is continuous with the crest opposite the valleys where it has not been cut away. Sections on the inner face of the moraine opposite the divides, however, frequently show rock in place; and while this inner slope is drift-covered, it appears that the drift forms but a veneer over the truncated spurs of the rock divides between adjacent lateral valleys, so that the apparently simple moraine along the base of Lost Canyon Mountain is really a cut-and-fill affair, moraine-veneered truncated spurs opposite the divides, and typical moraine embankments opposite the lateral valleys. This double character holds for four miles along the south side of the valley, and for a short distance along the north side back of Twin Lakes village.

4. *The Clear Creek morainic system.*—This paper is concerned with the Lake Creek region, yet it is permissible to note that the history which has been outlined above for the glacier occupying the valley of Lake Creek was duplicated in every essential feature by the

glacier occupying the valley of Clear Creek, four miles to the south. Here are two series of moraines. An inner one of late date is represented by two great lateral embankments rising 1,000 feet above the valley bottom of Clear Creek and extending to the Arkansas. These laterals do not unite toward the valley, but the lower moraines of the same age between them are connected with gravels which follow down the gorge of the Arkansas at levels not far above the river. Outside the younger moraines there are, both north and south, extensive areas of older moraine, better developed even than about Lake Creek, and associated with higher gravels which lie above and outside of the Arkansas gorge, and indeed are continuous with the higher gravels about Lake Creek. The same differences in expression, in weathering, and in dissection by streams hold here between the earlier and later moraines and gravels as in the valley of Lake Creek, and make less probable any serious mistake in the interpretation which has been given to the features of that basin.

II. PLEISTOCENE HISTORY OF THE UPPER ARKANSAS

1. *The terraces of the earlier glacial period.*— One of the most striking geological features of the Arkansas Valley is the great development of the high-level gravels. From Granite, for a distance of 10 miles to the north, they occur nearly continuously on the west side of the river. Opposite Hayden, on the east side of the river, the graded rock-plain which has been noted as occurring to the south, becomes covered by an extensive alluvial fan similar in physical composition to the gravel terraces west of the river, with its lower edge forming a terrace of the same altitude as the terrace on the west, but rising steadily from this height back toward the gulches which head in the Park Range back of Leadville. The earlier glacial period was a time of ice-erosion. The streams leading down from the glaciers were overloaded, aggrading was the rule, and extensive wash-plains were formed. In the Arkansas valley aggrading went on until the stream was flowing many feet, in some cases many scores of feet, above its earlier level. Wash-plains extended continuously along the main valley, and vast alluvial fans extended down from the glaciated mountain valleys on either side. About Leadville these fans are largely intact today; but on the west they do not seem to

have been so extensively developed, and are now found in distinct, but not conspicuous, remnants on the shoulders of Mount Massive between the glaciated valleys.

Emmons[1] and Hayden[2] have suggested that the gravels are lake deposits of an interglacial period. They do not seem to be interglacial deposits, as they are closely related to the earlier moraines; and interglacial time was an epoch of valley-cutting and not of valley-filling. But are the gravels lake deposits? To the writer there is nothing to suggest that they are not stream-built gravel-plains. The material is mainly coarse, bowlders up to one and two feet in diameter being very abundant. It is slightly or not at all stratified. Where coarse gravel and fine gravel alternate there is a rude stratification, but in the coarse gravel stratification is wanting. If the material had been deposited in a body of standing water, a marked development of foreset beds (delta structure) should be found throughout the gravels; but any such structure is lacking. At one point only was any considerable amount of fine material noted, just north of Cache Creek (Fig. 1, 5), at the base of Lost Canyon Mountain. Here there is a considerable body of fine gravel, and some clay, in the plain. This is explained by the protected position, between the points of discharge of Lake Creek and Clear Creek. It is probable that the more rapid building up of the plain both to the north and south may have left depressions which might be filled with finer material or even clay, but such deposits of fine material are very local.

Not only the character of the gravels, but the disposition of the surface, indicates stream-work. Emmons notes that south of Leadville the gravels occur on the spurs back from the river at an elevation 1,000 feet greater than along the river, and infers the elevation of the Park Range over the valley by that amount. But a similar rise of the gravels occurs west of the Arkansas, though the gravels do not reach the altitudes they do near Leadville. Gravel fragments occur on the foothills of Mount Elbert several hundred feet above the level of the terrace along the river. These gravel terraces rising

[1] Emmons, *Geology and Mining Industry of Leadville*, Second Annual Report, U. S. Geological Survey, pp. 220, 229.

[2] *Annual Report* for 1873, p. 53, and for 1874, p. 52.

toward the mountains have every appearance of alluvial fans. To the writer, who came into the region after several weeks in the Utah portion of the Great Basin, where the long slope of alluvial wash at the base of the mountain ranges is a striking feature, their topographic resemblance to alluvial fans was very strong.

The question may be raised as to the possibility of damming by the glaciers entering the Arkansas valley. The moraine of the earlier Lake glacier does not appear to have reached the present Arkansas by a half-mile, and cannot have dammed up the stream. Further the height of the gravels above and below Lake Creek is essentially the same. At Clear Creek the conditions are different. Here the old moraine lies along the western edge of the gorge, and the height of the gravels to the north seems to be determined by the rock-level at the top of the gorge outside of the moraine. The Arkansas was pushed to its present position on the east side of the valley by the advancing moraine of the Clear Creek glacier, and the height of the gravels up-stream determined by the position of that moraine. This does not necessarily mean, however, that a lake was formed to the north; the character of the gravels is against that interpretation. The probable explanation is that in earlier glacial time the advance of the Clear Creek glacier and moraine went on contemporaneously with aggradation by the Arkansas, until at the maximum the Arkansas was flowing on its flood-plain about the nose of the Clear Creek moraine, pushed to that position by the gradual advance of the glacier. Farther north also the Arkansas hugs the east side of its valley. This, however, is not due to pushing by glaciers, but probably to a greater supply of detritus coming in from the glaciated valley of Lake Creek, building a wash-plain with slope to the west, and constantly tending to push the main stream to the east.

2. *The work of interglacial time.*—Glacial periods are times of valley-clogging; interglacial periods, of valley-cutting. The first glacial period with its moraines and gravels was succeeded by an interglacial period in which the Arkansas and its tributaries were engaged in valley-cutting. To this period is assigned the excavation of the rock-gorge of the Arkansas. From a point two miles north of Lake Creek, south to beyond Granite, the Arkansas was flowing on the east side of its own gravel deposits and well to the east of its

earlier course. Here it quickly sunk its channel through the gravels into the underlying granite, and its interglacial valley is in consequence narrow and gorge-like. North of its rock-valley, toward Leadville, the Arkansas does not flow in rock, and its interglacial valley is much wider, averaging three-quarters of a mile, though not less deep than to the south. This difference in valley-width is, of course, due to the difference in hardness of the materials in which the valley has been opened. There is probably a double reason for the failure of the river to lay bare rock to the north. North of Lake Creek glaciers occurred on both sides of the valley, there was not the unsymmetrical development of wash that farther south forced the river to hug the east side of the valley, and it therefore kept more nearly its preglacial course. Further, the preglacial Arkansas was flowing in a graded rock valley which probably had a gentle gradient, while the interglacial gravels were laid down by rapid streams handling coarse material and building that same material into steeper slopes. Later erosion would naturally reach rock more generally along the lower course of the river where the gravels were less thick.

As the Arkansas cut its valley during interglacial time, the side streams were lowering theirs. Those from the east were flowing over a rock-graded plain thinly veneered with river gravel, and as they cut down, they dissected the plain and largely removed the gravel, so that now it occurs only in scattered bowlders over the divides between the tributary streams. The slope of these tributaries from the east steepens toward the main stream; they have not quite been able to keep up with the main stream in downward cutting. The small stream which enters the Arkansas through drift from the west at Hayden has swept away the whole terrace for a half-mile in width along its lower course, and at Lake Creek the terrace has been quite cleared away west of the river. No permanent streams enter the Arkansas between these two, but wet-weather streams originating on the old moraine and terrace have cut out wide, shallow valleys, whose depth is determined by the ledge of hard rock which the streams have found at the edge of the river. North of Lake Creek this action has cut out several broad, transverse valleys, but has not destroyed the original surface of the higher terrace. Between Lake Creek and Clear Creek there are different conditions. Here several streams

come down the face of Lost Canyon Mountain, cross the plain, and enter the Arkansas. Only one of these, Cache Creek, is a permanent stream, but the others carry much more water than the channels which head in the moraine to the north of Lake Creek. The effect of their combined action is that the original surface has been cut into series of eastward-sloping terraces, whose level is determined by the distance the streams have cut into the rocky edge of the Arkansas gorge—levels which are lowest toward the south, where Cache Creek cuts deepest toward the river. These valleys have widened till they met, and in this manner the original constructional level of the terrace has been replaced by a terrace of stream-erosion. The only points where the original surface is kept are on the salients at the base of Lost Canyon Mountain, where the gravels have been protected from erosion by their position on the divide between the small valleys crossing the plain. Here the gravels rise to the level of the gravel fragments east of the river and north of Lake Creek. At one point nearer the river a remnant of the higher level is kept. A small hill just south of Lake Creek on the west side of the Arkansas rises 50 feet above the general level of the plain in its neighborhood. The part above the surrounding terrace-level is rock with a covering of gravel. This is a remnant, not of the original terrace, for it is covered with quartzite gravel derived from north of the Lake Creek region, but of an intermediate terrace which stood above the present terrace-level; and it is a witness to the general degradation of this part of the old plain. The Arkansas here cut across a shoulder of granite coming from the east, and this granite nucleus has preserved the gravel over it from removal.

The cutting of interglacial time was marked by the development of terraces (*F* in Fig. 3) at intermediate levels. The benches so produced are not conspicuous features of the topography, and are determined by the levels at which the streams came upon rock barriers as they cut through the gravels to the underlying rock. One such terrace is cut in the high gravels along the east side of the Arkansas opposite Hayden, and is determined by the highest rock-level in the gorge to the south. At this level in the gorge a narrow terrace is worked out in the rock. The gravel on these intermediate terraces is largely composed of quartzite bowlders of medium size, while the bowlders of the upper terrace are largely granitic in composition and

contain only an insignificant amount of quartzite. Quartzite is abundant in the Park Range about Leadville, but is not found on either side of the valley about Lake and Clear Creeks. This difference in rock composition of the terrace gravels indicates that the upper gravels about Lake Creek were almost wholly composed of material swept in from the adjacent valleys, while during interglacial time the Arkansas was sweeping that material away and bringing large amounts of material down from the upper parts of the valley. Incidentally it means that in early interglacial time continuous gravel trains, above the level of the rock in the gorge, extended up towards the head of the valley.

3. *Second glacial and postglacial.*—The later glacial period marked a new advance of the ice, the accumulation of the younger moraines, and the development of a valley train in the rock-gorge of the Arkansas, but was not marked by any change in the course of the river. The later gravels occur in scattered terrace fragments north to Granite Gulch. North of that point they are not distinct. Postglacial time has been marked by the resumption of clearing by the stream, and the removal in large part of the terrace made during the later glacial advance.

III. GLACIAL EROSION

1. *Valley form.*—The cross-profile of a maturely glaciated mountain valley will be typically as shown in Fig. 4; a broad U-shaped valley below, surmounted by gentler, but still steep, slopes (*AB*) made by undercutting, which, in a region not too thoroughly glaciated, will pass above into the gentle slopes (*AC*) of preglacial origin. The most striking feature of a view along such a valley will be its broad U-trough. This form is well shown both in the main valley of Lake Creek and in those of its tributary valleys which were occupied by ice. The best illustration is afforded by the middle and upper part of Willis Gulch. No hanging valleys above, and no rock-sills or buttresses below, mar the simplicity of its general form. It is a remarkably regular example of the type. The middle part of several

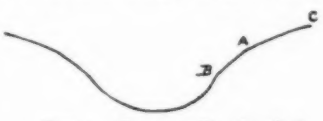

FIG. 4.—Cross-profile of a glaciated valley.

other tributaries which were occupied by valley glaciers show the same general features. See in this connection Fig. 10.

The main valley above Twin Lakes shows the same broad U-cross-section, but in the matter of broad detail there are serious interruptions to the regular profile, in rocky barriers across the stream-floor, and in some cases in buttresses standing out prominently from the valley side. The longitudinal profile of the valley is not even. For a distance the stream may be swinging from side to side in an alluvial valley floor, and then may for a fraction of a mile be flowing with more rapid fall in a rock-gorge between the low, rolling, glaciated hills of one of the valley-sills. Four such sills occur in the main valley within a distance of six miles above the mouth of the rock-gorge. The largest is the one at the mouth of the rock-gorge. It consists of a series of rounded rock-bosses rising to the higher walls of the valley on either side, but is most conspicuous on the north, where it forms a long rocky barrier, reaching nearly to the upper limit of glaciation. The difference in level of the stream between where it enters this rocky portion of its valley above, and where it leaves it below, is 600 feet; and it is here flowing for a mile in a narrow postglacial gorge. Other sills occur at several points upstream, but are not as conspicuous as the one at the mouth of the rock-valley.

Rock-bosses standing out from the valley wall also occur. The two on either side of Monitor Gulch are the best—Monitor Rock[1] on the west side, and another nearly as high on the east. Monitor Rock rises nearly 1,500 feet above the valley floor, nearly to the upper limit of valley glaciation, and stands out conspicuously into the valley.

An even U-trough is the ideal toward which the glacier tends to shape its bottom; but rock-sills and buttresses show that in the process of valley-cutting the glacial bottom may be fashioned quite irregularly, on account of differences either in rock-resistance or in glacial erosion at different points. Monitor Rock may be due to difference in rock hardness, as it is composed in part of a finer grained, denser, and probably more resistant facies of the porphyritic granite which is the common rock of the valley. But it is not pos-

[1] Described by Hayden, *Annual Report* for 1873, p. 54.

sible to make any general statement as to the greater hardness of the rock barriers, because much the same kind of rock is found all along the valley. In the present case these irregularities occur well below the limit of hanging valleys, and so in that part of the valley excavated by the glacier; they are not due to subaërial erosion, though the prominence of projecting buttresses may have been so increased.

The separation of the different elements of the valley side indicated in Fig. 4 is difficult, on account of weathering and of the indefiniteness of the upper limit of glaciation. The upper preglacial slope is easily recognized in the rounded summits of the divides

FIG. 5.—Monitor Rock, Lake Creek Gorge, looking down the gorge.

between the tributaries to Lake Creek. It is a graded slope of about 10°, is usually grassed over, and is shown where the divides between the tributaries have not been sharpened by glacial erosion. But it is not easy to distinguish the cliff of glacial abrasion from the oversteepened cliff above the former glacial bed. The glaciated valley surfaces have been largely destroyed by subsequent weathering, and where the height of the glacier was changing, it may easily have been that the passage from a well-glaciated wall below to a non-glaciated wall above was originally gradual and indefinite. In the lateral valleys weathering has practically destroyed all the glacially smoothed surface of the valley walls, and the upper limit of glacial erosion can be made out only approximately. In the main valley the upper limit can be more definitely fixed, and while even here there is doubt about its exact location, a lower portion of the valley wall can be recognized, showing under favoring conditions well-developed glaciated surfaces, while an upper, steep, rocky portion

seems to have been above the ice-level, and to have been formed by undercutting, or sapping, of that part of the valley side above the glacier surface. The ridges between some of the more vigorous lateral valleys, as between Crystal Lake and Willis gulches, seems to show this intermediate slope due to glacial sapping. The pre-glacial slope has been destroyed by valley-cutting, but the steep slope of the upper glaciated valley gives place to a gentler, but still steep, slope, which is best explained by glacial sapping. The same element in the valley slope is shown in the upper angle of the truncated spur in the main valley shown in Fig. 9.

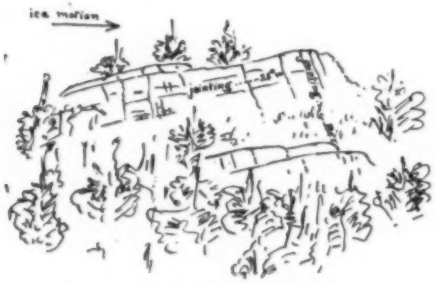

FIG. 6.—Glaciated and jointed ledge.

2. *Glaciated surfaces.*—Glacially smoothed surfaces are common in the main valley, especially so on the rock-barriers and rock-bosses which were peculiarly exposed to glacial erosion. In the matter of abundance of glaciated surfaces there is a great difference between the main valley and its tributaries. The larger lateral valleys, such as Willis Gulch and Crystal Lake Gulch, have suffered an almost complete destruction of their glacial surfaces. At one point on the wall of Willis, glacial smoothing was recognized, and in Crystal Lake Gulch a small area on the west wall, and a certain amount of smoothing on the hummocky surface of the cirque floors, are all. Some of the other gulches show even less remnants of glacial surfaces than do these two. Glacial striæ are found only on the more perfectly preserved surfaces in the granite of the main valley.

A matter of importance is the proportional amount of erosion due to glacial abrasion or glacial plucking. In almost all cases rock-ledges and rock-bosses show a great difference between the stoss and lee ends. The former are apt to be well-rounded; the latter, almost invariably steep and coarse-hackly. The jointed structure of the granite in the main valley is such as to favor plucking. The accompanying figure (Fig. 6) of a glaciated ledge on the north side of the valley

brings this out. Three prominent series of joints intersect the granite. The direction of ice-movement is toward the east. One series of joints has a dip of 70° E., and so runs almost at right angles to the direction of ice-movement, and gives easy conditions for plucking. Two other series of joints dip respectively steeply to the south and more gently to the north, while the blocks into which they divide the rocks pitch to the west. The result on the form of the ledge is shown in the figure in which the glaciated surface rises to the east, evidently determined by the jointing. When a ledge cut out from a rock jointed in this manner is seen end on, it usually shows a composite profile and not a simple glaciated curve, the profile being

FIG. 7.—Glaciated ledges on south side of Lake Creek.

clearly controlled by the jointing. The connection between jointing and glaciated surface in such instances means that plucking has played a large part in glacial erosion over the surface, as well as on the lee side of the boss and that a process of pluck and heal has been going on, the ice breaking out great blocks along planes determined by jointing, and then rounding off the broken edges by glacial abrasion. This form of ledge surface is not a matter of occasional outcrops; in the middle part of the valley the whole valley sides for a distance of hundreds of feet vertically, and for considerable distances along the valley, shows this intimate relation between joints and form of the rock outcrops. On the south side of the valley, on both sides of Crystal Lake Gulch, glaciated rock outcrops (Fig. 7.) rise from the stream to the upper limit of glaciation, and all show glaciated stoss sides rising at an angle of 30° toward the east, and ending in a lee slope plunging steeply to the east. The two structures are determined by the line of jointing in the granite. Farther up the valley,

near Everett, an extensive area of glaciated ledges on the south side of the valley shows the ledges sloping to the east—again an expression of rock-jointing, which in this case holds a different direction from that farther down-stream. Facts of this kind, occurring through the valley, point to glacial plucking as being as important as, perhaps much more important than, glacial abrasion in the erosion of Lake Creek valley.

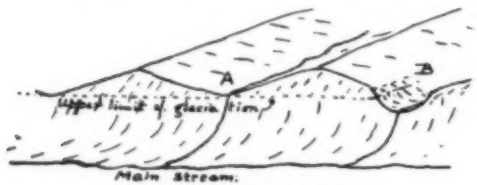

FIG. 8.—Diagram of hanging valley.

Other minor features of glacial smoothing are illustrated at different points in the main valley. Evenly rounded ledges of considerable size, shallow saucer-shaped (in cross-section) furrows, glacial undercutting, and in some cases a smoothing of parts of the protected lee sides of eminences, also occur. A feature noticed in one or two cases was the production of nearly flat, smoothed surfaces intersecting at a small angle, and separated by a sharp ridge, the whole being worked out of sound rock. Evidently some change in the current of the ice had taken place at that point. Of similar nature is the gouging of a flat surface by a shallow groove, much as a shallow groove might be cut in a planed board by a gouge of large curve.

3. *Hanging valleys and truncated spurs.*—When the main valley of a preglacial drainage system has been deepened by glacial erosion, the relations which should exist after the disappearance of the ice may be represented by Fig. 8. The spurs of the old divides and the lower ends of the tributary valleys have been cut away, giving hanging valleys and truncated spurs. It is not essential that the upper limit of glaciation should coincide with the level of the lateral valley, as it does in this figure. The tributary valleys may or may not have been occupied by glaciers. If they have been so occupied, the form of the hanging valley will be like *B* in the figure, broad and U-shaped; if not, like *A*, more or less broadly V-shaped, according to the steepness of the preglacial valley. Terminal facets marking truncated spurs, and both glaciated and non-glaciated hanging valleys, are found along the sides of the Lake Creek valley.

One of the best illustrations of terminal facets separating non-glaciated hanging valleys occurs just above the mouth of the gorge on the south side of the valley. The ice here reduced the valley side to an even curve leaving the wall not at all broken by rock buttresses. In this manner a series of triangular facets was formed against the divides between short tributary valleys, which right here were not occupied by glaciers. Subsequently interglacial and postglacial erosion have cut these valleys further toward the main valley floor, and have furrowed the facet faces, but they still distinctly show their faceted character. The facet shows steeper in the lower three-fourths of its face, a gentler, but still steep slope, above to the apex of the facet. In Fig. 9 the dotted line *AB* marks the upper limit of glaciation; the part of the facet below that line seems to represent glacial abrasion, the upper part the work of glacial sapping. The truncated spurs along the base of Lost Canyon Mountain have already been mentioned (p. 292) while speaking of the moraine.

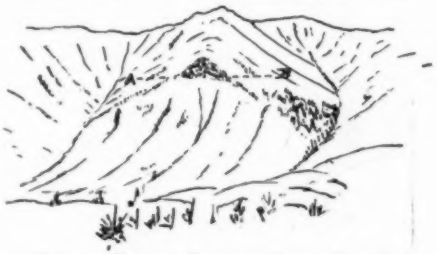

FIG. 9.—Truncated spur on the south wall of Lake Creek Valley.

Hanging valleys and truncated spurs obviously go together, and hanging valleys are a characteristic feature along Lake Creek. Some of these hanging valleys were occupied by glaciers, some not. Crystal Lake Gulch, La Plata Gulch, and La Plata Basin are glaciated hanging valleys. Willis and Boswell gulches to the east were glaciated valleys, but are not hanging valleys, as the main glacier did not cut below the level of the tributary valleys in this lower part of its course. Of the three mentioned, that of Crystal Lake Gulch is most characteristic. Fig. 10 shows this hanging valley as seen from the opposite side of the main valley. It is a broadly opened U-valley, ending on the side of the main valley about 1,000 feet above Lake Creek. La Plata Basin and La Plata Gulch, the two tributary valleys from the south, next west of Crystal Lake Gulch, and Hayden Gulch, entering from the north opposite Crystal Lake Gulch, are hanging valleys of similar type. The other tributary

valleys which enter Lake Creek above Twin Lakes are either short V-valleys, unoccupied by glaciers, or occupied only by masses of ice forming cirques at their head, or else are, like Echo Gulch, U-valleys in their middle and upper course, and V-valleys below, the ice-tongue not having reached the main valley.

4. *Two periods of glacial erosion in the gorge.*—The moraines of the Twin Lakes glacier show two glacial periods separated by a long

FIG. 10.—Hanging valley of Crystal Lake Gulch.

interglacial period, during which the cutting of the rock-gorge of the Arkansas took place. Only portions of the earlier moraine remain, but they show that certainly in part, and probably on the whole, the earlier glacier reached farther into the valley than did the later glacier. The gravels associated with this earlier moraine are much greater in bulk than those associated with the later moraine. The material of the moraine was obviously derived from the valley of Lake Creek, and the great abundance, in the gravels, of material derived from the valley of Lake Creek indicates that the gravels

were largely from this same area. These things suggest strongly that the material removed from the valley during the earlier period of glaciation was as great, and probably greater, in amount than that removed during the later glaciation. The question naturally rises: Is it possible to detect in the rock valley of Lake Creek evidence of these two glaciations, which we know must have occurred? It is not easy, since the work of the later period would continue that of the earlier, and all products of erosion would be removed from the valley. But it is thought that evidence in favor of two periods of glacial erosion, with the larger amount of work done in the earlier period, is found in the relation of the hanging valleys to the main valley.

In typical hanging valleys the contours of the lower slopes of the main valley continue unchanged beneath the hanging valley. A

FIG. 11.—Profile of hanging valley.

cross-section of the main valley and long profile of the lateral hanging valley is given in Fig. 11, in which *AB* is the longitudinal profile of the hanging valley. But the profile of the typical hanging valley of the Twin Lakes region would be represented by *AECD*, the triangle *ECB* representing a narrower or broader notch which has been cut out from the side of the general valley immediately below the hanging valley. Such a re-entrant could conceivably be cut out by the main glacier, or by the lateral stream. There seems to be no good reason why the ice should favor the side wall beneath the hanging valleys generally, and in some cases these cuts are too sharply re-entrant for ice-work. Further, these notches contain in almost all cases morainic material; and this is the case whether the lateral valleys were occupied by ice or not. They are areas of glacial deposit rather than of erosion. Their origin seems to be as follows: During the earlier period of glaciation the main glacier cut its valleys below the level of the tributary valleys, producing normal hanging valleys, the longer of which were occupied by tributary

glaciers and became U-valleys, the shorter being hanging V-valleys. During the succeeding interglacial period the tributary streams cut back the mouths of their hanging valleys for a greater or less distance, forming V-valleys or ravines at the lower end of the U-valleys, and deepening the V at the lower end when the valley had not been previously glaciated. The glacier of the second period smoothed the walls of these interglacial stream-cut re-entrants where they were not too sharp, but in practically all cases dumped more or less morainic material into them. Postglacial time has enabled the streams for the most part to cut through this drift, and below the mouth of the hanging valley they follow a steeper course, chiefly in morainic débris, but occasionally cutting into the solid rock. This interpretation of the phenomena at the mouths of the hanging valleys implies that the larger features of the forms of the glacial valleys were assumed in earlier glacial time—an inference in accord with the evidence of the moraines.

POSTGLACIAL CHANGES

Since the final disappearance of the ice, many changes of minor importance have taken place, in the way of both erosion and deposition. Streams flowing across drift and across rock barriers in the valley of Lake Creek have cut their channels. Behind the recessional moraines of Lake Creek considerable deposition has taken place, forming the extensive meadow at the head of Upper Twin Lake, and smaller patches of bottom-land further up-stream. The most conspicuous changes, however, are the rock-weathering and landslides along the main valley of Lake Creek, but especially along and at the head of its tributary valleys. The almost entire destruction of glacially smoothed surfaces in the tributary valleys has been mentioned. Here, at altitudes near and above the timber line, there has been a steady rain of rock fragments from the valley sides, and talus cones are everywhere present, mantling the lower parts of the gulch walls, and in many cases merging to make a nearly continuous talus slope. In addition to this gradual accumulation of fallen blocks to make a talus slope, great masses of broken rock have fallen from the sides and shot out to or beyond the axis of the valley. In one case, in the upper end of Willis Gulch, for a distance of half a mile along the valley side, and for a height of 1,000 to 1,500

feet above the valley bottom, the rock along the side of the gulch has slipped down and out in a series of lobes whose festooned and ridged surfaces express the flow within the mass of the landslide. In a number of instances landslides have dammed up the streams and caused small lakes; indeed, the small lakes in the gulches are almost uniformly formed in this way, and lakes occupying rock basins are rare.

MOUNTAIN FORM

Mountain form is an expression of two factors: rock structure, including original form and internal arrangement, and erosive processes. So far as the first of the two factors is concerned, conditions in the Twin Lakes region are simple. The rocks are all completely crystalline, and are granite, granite porphyries, and granitic gneisses. Their composition is such that no great difference may be expected in resistance to weathering, and their surface distribution bears this out, for they appear to be largely independent of topography. The porphyritic granite has already been referred to as one of the rocks most characteristic of the valley of Lake Creek, and it is possible that its somewhat greater capacity for weathering may have determined the course of the preglacial Lake Creek; but the ridges which separate the valleys tributary to Lake Creek are in places porphyritic granite, in places gneiss, and the difference in the rock seems to make but little difference in the character of the divides. In some instances the jointing of the rock plays a part in shaping minor details of form, the rough serrate ridges about La Plata being worked out on a jointed compact gneiss which holds its form well and gives the peculiarly jagged outlines to the lower divides; but petrographically the Twin Lakes area is a granitic complex, and differences in form are to be explained by differences in the character of the erosive processes.

The erosive processes which have been at work in the area are two, stream-erosion and glacial erosion. The larger features of the region were worked out by streams in preglacial time. These larger features were profoundly modified in places by ice-erosion in Pleistocene time.

The preglacial topography of the Arkansas valley and of the adjacent Park and Sawatch ranges can only be inferred from those

portions of the region which were not subject to glacier-erosion during the Pleistocene, and have thus retained their preglacial form essentially unchanged to the present. The character of this topography was suggested in the opening pages of this paper. Briefly it was as follows: the Arkansas was flowing in a broadly opened graded valley between ranges which rose on either side to a height of from 3,000 to 5,000 feet, but which were characterized by rela-

FIG. 12.—Lost Canyon Mountain from the Arkansas Valley.

tively gentle and graded slopes. The term most applicable to such mountains is "massive." A view of Lost Canyon Mountain (Fig. 14) from the Arkansas valley is probably typical for the mountain range in general in preglacial time.

The study of mountain form about Twin Lakes is the question how far in any particular locality this preglacial type of mountain has been destroyed by glacial erosion; how far cliffs, arrêtes, and peaks of glacial origin have replaced the more gentle and even slopes of mature subaërial erosion. Back toward the divide of the Sawatch

Range, where the head-feeding valleys of the glacial streams were working against each other, cirque action was general, sharp forms prevail, and the general view looking west toward the divide from any high point near the Arkansas shows a sea of sharp peaks. The multiplication of tributaries back in the range leaves scarcely any part untouched by glacial action. Fig. 14 is a view taken looking

FIG. 13—Summit of Lost Canyon Mountain, with the upper edge of Boswell Gulch cirque on left.

across Lake Creek toward La Plata Peak (14,342 feet), and shows something of the character of the area where little preglacial surface is left, the ridge in the foreground on the right being the only preglacial surface in the view which shows. About Twin Lakes, and nearer the border of the valley, there are considerable areas in which the two types of topography resulting from the two agencies occur together, since here the drainage of the tributaries of the Arkansas is concentrated in trunk channels of their lower course. The general form of Lost Canyon Mountain as seen from the Arkansas valley has been mentioned. Fig. 13 shows the evenly rounded summit of pre-

glacial date at a height of 12,800 feet above sea-level. The steep slope on the left is the upper edge of Boswell Gulch amphitheater, and is of glacial origin, and the view shows the manner in which cirque-action was gnawing into the preglacial topography at the close of the last glacial period.

In using the present topography of the non-glaciated areas about

FIG. 14.—La Plata Peak from the north side of Lake Creek.

the Upper Arkansas to illustrate the preglacial topography, it is assumed that substantially no change has taken place in those areas since the commencement of glacial time. Strictly this is not true, as these areas were subjected to subaërial erosion during Pleistocene and post-Pleistocene times; but it is not believed that the kind of changes then going on was different from the changes of preglacial time. Nor does it seem probable that the amount of change which has taken place since the commencement of the Pleistocene would be great for an area which had then reached maturity under atmospheric and stream agencies.

THE VARIATIONS OF GLACIERS. IX[1]

HARRY FIELDING REID
Johns Hopkins University

The following is a summary of the Ninth Annual Report of the International Committee on Glaciers:[2]

REPORT ON GLACIERS FOR 1903

Swiss Alps.—Of the ninety glaciers under the care of the Swiss foresters, fifty-eight were measured in 1903; the larger number, forty-three, are receding or stationary, and this is evidently the condition of the large majority of the Swiss glaciers. The slight tendency to increase shown last year by thirteen glaciers continues. Three glaciers have been certainly increasing for the last three years; twelve have been increasing for a year or two.

Between 1902 and 1903 the Rhone glacier has receded 11.5^{m} and has uncovered an area of $4{,}900^{sq\,m}$. There have been a slight thinning in the lower part of the glacier and a slight thickening higher up.[3]

Eastern Alps.—We have reports from twenty-nine glaciers, eighteen of which are retreating, six are about stationary, and five are advancing.

In the Silvretta group, two glaciers continue to retreat. The Suldenferner in the Ortler group has advanced more than 70^{m} between 1895 and 1903, nearly one-half of which occurred between 1901 and 1903. This glacier is being carefully observed. In the Oetzthal the Hochjochferner and the Hintereisferner are retreating, whereas the Vernagtferner and the Diemferner show slight evidence of advance. The Hochjoch has retreated 2.3^{m}, and the Vernagt has advanced 5^{m}. The Hintereis is growing thinner in the lower part,

[1] The earlier reports appeared in the *Journal of Geology*, Vols. III–XII.

[2] *Archives des sciences physiques et naturelles* (Geneva, 1904), Vol. XVIII, pp. 160–95.

[3] Report of Professor Forel and M. Muret.

but has become slightly thicker in the upper part. The glaciers of the Stubaï group, which, in general, have been retreating since 1891, are now retreating much more slowly; and one of them, the Sulzenauferner, has advanced 6.5^{m}. In the Zillerthal the Rainbachkees has retreated 4.4^{m}. Six glaciers of the Venediger group are retreating quite rapidly and three are about stationary. The glaciers of the Glockner are all retreating. Two glaciers of the Ankogel group, the Hochalmkees and the Kleinelandkees, are retreating at the rate of 7 or 8^{m} per year. The Grosselendkees, on the other hand, lying between the other two, has advanced over 2^{m}.

Italian Alps.—Two secondary glaciers of the Marmarole group are retreating. The other glaciers of the Venetian Alps are retreating slightly or are stationary. All the snow-fields of the Cavallo have increased considerably in size, whereas those of the western slope of the Zoldo have diminished very much since 1888. The glaciers of the Graian and Pennine Alps, in general, have retreated slightly. There seem to be marked increases in the accumulation of snow in the reservoirs of the Brenva glacier and of the glaciers on the Grivola and Grand-Paradis. A discussion of all the observations at hand regarding the glaciers of Valnontey has shown indirectly, but rather strikingly, the slight advance of 1891 which, unfortunately, was not actually measured.[1]

French Alps.—The second report of the French Commission on Glaciers, published in 1903, contains a detailed account of many glaciers and a very comprehensive review of glaciology.[2]

A number of glaciers of Mount Pelvoux advanced slightly in 1890–91, but have retreated ever since; and many of the smaller glaciers have diminished so much in size as to indicate that they may disappear altogether. The glaciers of the Grandes-Rousses have been retreating for the last thirty years, with a slight interruption for some of them about 1890. The glaciers of the Maurienne and of the Tarentaise have shown changes in opposite directions, but for the great majority the retreat has continued, with a tendency toward a slower retreat for the larger glaciers. It is rather interesting to note that the largest glaciers have retreated the least. A comparison

[1] Reports of Professors Porro, Marinelli, and Marson.

[2] By M. Charles Rabot.

of the present position of glaciers with their positions indicated on the maps made about forty years ago shows that the average annual retreat during that period has been about three times as great as the annual retreat during the last decade.[1]

Scandinavian Alps: Norway.—The glaciers of the Jotunheim show, in general, a slight advance between 1901 and 1903. In this region the snowfall has been unusually heavy, some of the glaciers being entirely covered with snow throughout the whole summer of 1903. The same can be said for the glaciers of the Folgefon. There has also been an excessive snowfall in the Jostedal, but the glaciers there have continued to recede slightly.[2]

The Caucasus.—A number of new glaciers have been visited and described, but no information is given regarding their variations, with the exception of one on Mount Bazar-Duzi, which seems to be in retreat.

The Tyan Shan.—In this mountain chain the snowfall has increased very materially. In June, 1903, the glaciers seem to have been entirely snow-covered. A record of the rainfall in the neighborhood shows that it was more than twice as great in 1902–3 as in 1900–1. A glacier resembling the Mer de Glace, and as large as any in the Alps, has been discovered and mapped in the Alatau Mountains of Ili.

Canada.—After an almost normal winter, the observed glaciers in British Columbia and Alberta exhibit most interesting changes since last year. Of the four carefully observed, two are advancing and two continue to recede.

The Victoria glacier, Alberta, continues to recede and also to contract in width. The average shrinkage on the northwest side for the past three years is nineteen feet per year. There is a very evident decrease in the thickness of the ice, and an increase in the number of crevasses at the upper part of the left-hand side. The tongue, deeply buried in moraine, is evidently receding.

The Wenchumna glacier, Alberta, has apparently been advancing for a number of years; it has not been visited until recently, so that the rate of advance cannot yet be determined. Its condition is evidenced by inroads into a living forest composed of large trees which

[1] Report of Professor Killian. [2] Reports of Messrs. Oyen and Reckstadt.

are being plowed down by great masses of moraine advancing before the ice.

The Illecillewaet glacier, British Columbia, continues to recede and to decrease in thickness. The following table shows the yearly recession determined annually in August since 1898:

1898–1899	11 feet
1899–1900	69 feet
1900–1901	15 feet
1901–1902	48 feet
1902–1903	33 feet

A careful triangulation of the plates placed on the ice in 1899 to determine the rate of flow proves that the rate determined in 1900 has subsequently remained almost constant.

While the Asulkan glacier has apparently shrunk in breadth, the tongue continues to advance. The following shows the principal changes yearly since 1899:

1899–1900	recession, 24 feet
1900–1901	advance, 4 feet
1901–1903	advance, 36 feet[1]

REPORT ON THE GLACIERS OF THE UNITED STATES FOR 1904[2]

Professor George Davidson has made a careful study of all the old charts and narratives relative to the glaciers along the Alaskan coast.[3] He has incorporated in his account copies of some early maps, and has superposed upon them the outlines of the latest maps, and by this means has shown changes that have occurred in the position of the ends of some glaciers. The account is very full, giving, with references, all the descriptions of glaciers by the early navigators. Professor Davidson's general conclusions are practically the same as those arrived at by the Harriman Expedition, namely, that there has been a very marked general retreat of the glaciers,

[1] Report of Messrs. George and William S. Vaux, Jr.

[2] A synopsis of this report will appear in the *Tenth Annual Report of the International Committee*. A report of the glaciers of the United States for 1903 was given in this *Journal*, Vol. XII, pp. 258–63.

[3] "The Glaciers of Alaska That Are Shown on Russian Charts or Mentioned in Older Narratives," *Transactions and Proceedings of the Geological Society of the Pacific*, Vol. III, Ser. II, pp. 1–98.

with some exceptions, among which are the glaciers southwest of Mount Fairweather.

The two glaciers of Taku Inlet were greatly effected by the earthquakes of 1899, but are apparently making up a part of their losses. (*Davidson.*)

There are a large number of small glaciers at the heads of the valleys tributary to Lake Chelan, Washington. One of these, at the head of Railroad Creek, has retreated 200 feet in recent years; and other glaciers in the neighborhood also have the appearance of being in retreat. (*Rusk.*)

The snowfall in the neighborhood of Mount Hood was unusually large in the spring of 1904, as it has been for the last few years. (*Gorman.*) Nevertheless, the Zigzag glacier on the west side of Mount Hood seems to have become smaller since last year. (*Knapp.*) The snowfall was very heavy in the Sierras this year; in the late summer the Lyell glacier was still almost entirely snow-covered, and deep drifts extended beyond the limit of the ice. It shows no definite retreat since Professor Russell visited it in 1883. The accumulation of snow seems to have been increasing during the last two or three years, and "there is good reason for believing that the glacier is slowly advancing." Lake Mono, at the foot of Mount Lyell, without any outlet, has been slowly rising for many years. This seems to ndicate an increase of precipitation in the region and may foreshadow a general increase in the size of the glaciers. (*Lee.*)

The Arapahoe glacier in Colorado shows no definite change since last year. (*Henderson.*) The Hallet glacier, a little farther north, has diminished in the last nine years, but there is no definite information with regard to its more recent changes. (*Mills.*)

The subject of glacial erosion is being vigorously attacked from the standpoint of physiography. Mr. Willard D. Johnson[1] describes the forms of old glacial valleys in the Sierras, dwelling especially on the very low grade, occasionally even reversed, in the upper part of the old glacial troughs. This form bears no relation to the profile produced by stream erosion, and he therefore thinks that it is to be accounted for by the erosion of the ice. He describes a descent into

[1] "The Profile of Maturity in Alpine Glacial Erosion," *Journal of Geology*, Vol. XII (1904), pp. 569–78.

the bergschrund of one of the smaller Sierra glaciers, where he found the rock impregnated with water melted from the ice, and the broken nature of the rock led him to believe that much sapping was accomplished at this point by the frequent freezing and melting of the water. This led to the belief that sapping of this kind explained the glacial erosion. Mr. Johnson has since given up this idea, because the bergschrund must be shallow in comparison with the depth of the ice; but he thinks that the line of the ancient bergschrund can still be recognized by a very steep cliff in the upper part of the walls of the cirques of the Sierras.

Mr. G. K. Gilbert[1] confirms the existence of a "schrundline," and brings out the interesting fact that a distinct difference in slope often exists on opposite sides of ridges in the high Sierras. The steeper side is that on which the snow would naturally accumulate as a result of the prevailing winds and of protection from the snow. He therefore concludes that the glaciers formed from the snow have by erosion steepened the slopes. In the volume of the Harriman Alaska Expedition on *Glaciers and Glaciation*, briefly noticed in last year's report, Mr. Gilbert presents a very strong argument in favor of the great erosive action of glaciers.[2]

Dr. Albrecht Penck[3] discusses the action of glaciers in the Alps, and shows how very difficult it is to explain all the physiographic features of glacial valleys without assuming that these valleys have been eroded by the glaciers.

[1] "Systematic Asymmetry of Crest Lines in the High Sierras of California," *ibid.*, pp. 579–88.

[2] *Glaciers and Glaciation*, Harriman Alaska Expedition, Vol. III (New York, 1904).

[3] "Glacial Features in the Surface of the Alps," *Journal of Geology*, Vol. XIII (1905), pp. 1–19.

THE ABSTRACTION OF OXYGEN FROM THE ATMOSPHERE BY IRON[1]

C. H. SMYTH, JR.
Clinton, N. Y.

That the affinity between oxygen and iron has been the chief factor in the concentration of the latter into workable deposits is one of the most generally recognized facts of chemical geology, although our knowledge of the details of the various reactions involved is far from complete. Indeed, there are few occurrences of iron ores in regard to whose precise method of formation there is not much diversity of opinion.

With ore deposits and with the details of genetic processes, the present paper is not concerned, its aim being to consider one broad result brought about by the chemical relations of oxygen and iron.

The question at issue is: Has there been a progressive oxidation of iron since the beginning of geologic time, involving the abstraction of oxygen from the atmosphere?

Several questions are suggested by the consideration of the main topic, but at present they can hardly be touched upon. Indeed, it is with considerable hesitation that the main theme is here presented, since the data for its thorough consideration are not yet available. But even if the conclusions reached must be regarded as to a high

[1] This paper was written in 1903, in the course of a general consideration of the circulation of mineral matter, and was laid aside for subsequent revision and elaboration, with the hope that further data might be obtainable.

The discussion of the same theme by President C. R. Van Hise (*A Treatise on Metamorphism*, Monograph XLVII, U. S. Geological Survey, pp. 950, 951) has suggested the publication of the paper, in spite of its lack of completeness, since the subject treated is of such a nature that a comparison of independently deduced figures, even though quite divergent, may be of value; and since, moreover, in spite of such divergence of numerical results, the final conclusion as to the importance of the problem presented is the same in both cases.

President Van Hise has been so kind as to read the manuscript, and has approved of the publication of its contents, for which courtesy the writer takes this opportunity of expressing his sincere thanks.

degree tentative, it is hoped that the mere formulation of the problem may be sufficiently suggestive to prove of some value.

Under atmospheric conditions, with abundant oxygen, iron is stable in the ferric condition, and during the circulation of mineral matter involved in the processes of denudation and sedimentation there would be, in the absence of opposing agents, a strong tendency toward the conversion of ferrous into ferric compounds, resulting, in the case of thoroughly disintegrated and decomposed materials, in a complete oxidation of the iron. The younger sediments, in so far as they are derived from other sediments, implying a thorough working over of their materials, would contain little or no ferrous iron. But opposed to this process we have the very potent reducing agent, organic matter. Not only does this agent, when present, take up oxygen that might otherwise combine with ferrous compounds, but it is also able to take oxygen from ferric compounds, reducing them to the ferrous state, thus counteracting the tendency toward oxidation above referred to.

According as the one or the other of these processes has predominated during geologic time, there has been a progressive oxidation or reduction of iron, and the rocks of the crust contain more or less ferric iron, while oxygen has been taken from, or added to, the atmosphere. If the processes balance, the ratio between ferrous and ferric iron remains constant, and the atmosphere is unaffected.

It is manifest that a solution of the problem would be afforded by analyses representing, on the one hand, the average composition, so far as ferrous and ferric iron are concerned, of the crust of the earth before denudation and sedimentation began; and, on the other, of the sedimentary rocks.

An approximation to the former is afforded by Dr. F. W. Clarke's[1] estimate of the composition of the "older crust," based upon 880 analyses of crystalline rocks.

For obvious reasons, a reliable estimate of the bulk composition of the sedimentary rocks is much more difficult to obtain, but the figures given by Stoke's analyses[2] are doubtless the best now available, and they are used as the basis of the present discussion. The samples for these analyses were prepared by Mr. G. K. Gilbert, in an effort

[1] *Bulletin No. 168*, U. S. Geological Survey, p. 14. [2] *Ibid.*, p. 17.

to get results that might represent the average composition of the sedimentary rocks, and there can be no doubt that the figures give a much closer approximation to the truth than would be afforded by a larger number of analyses taken at random. There is the further advantage that the analytical work is thoroughly reliable—a matter of first importance, and particularly so when it is a question of ferrous and ferric iron.

As in the analyses of limestones, the iron is all given as ferric oxide, the figures are not available for the present inquiry, but the iron content of these rocks is too small to be of great moment. An effort has been made to get from other sources evidence as to whether the correction for limestone would be plus or minus, but as most analyses combine the ferrous and ferric iron, and often the alumina as well, no definite conclusion was reached.

Not only does the small amount of iron in limestones affect the magnitude of this correction, but it is further reduced by the fact that the limestones are of minor moment in the mass of sediments. Gilbert[1] estimates the limestones as making up one-fifth of the total thickness of the sedimentary rocks. Reade's[2] estimate is one-tenth. Therefore, in view of the small percentage of iron in the limestones and their limited amount, they may be neglected without seriously affecting the results.

A more important question is that of the relative masses of shales and sandstones, and the consequent values to be attached to the figures for these rocks. No entirely satisfactory data are at hand to determine this point, but Gilbert's[3] estimate of equal parts of shale and sandstone is here used as being the best available.

As pointed out below, a change of this ratio would affect the magnitude, but not the sign, of the results. In the following estimates, therefore, the figures for shale and sandstone are given equal weight.

According to Clarke's estimate, the older crust of the earth contains 2.63 per cent. Fe_2O_3 and 3.52 per cent. FeO. The analyses of Gilbert's samples, by Stokes, give for shales[4] 4.03 per cent. Fe_2O_3 and 2.46 per cent. FeO. For sandstones[5] the figures are 1.24 per

[1] *American Geologist*, March, 1894, p. 214.

[2] *Chemical Denudation in Relation to Geological Time*, 1879, p. 53.

[3] *Loc. cit.* [4] *Op. cit.*, p. 17, column C. [5] *Ibid.*, column F.

cent. Fe_2O_3 and 0.57 per cent. FeO. These figures represent the results as stated in five distinct columns, in each of which the direction of the change is the same—an increase of the ratio of ferric to ferrous oxide as compared with the corresponding ratio in the old crust.

By combining the figures for shales and sandstones, we have, as an expression of the iron contents of the sedimentary rocks, excluding limestones, 2.64 per cent. Fe_2O_3 and 1.52 per cent. FeO.

Comparing these figures with those given above for the older crust, the contrast is pronounced. In the older crust the ferrous oxide is in excess, while in the sediments the ferric oxide is markedly preponderant. This relation is expressed by the following ratios:

In older crust, $FeO:Fe_2O_3::3.52:2.63$, or about 1:0.75.
In sediments, $FeO:Fe_2O_3::1.52:2.64$, or about 1:1.75.

In other words, in the old crust there is about three-fourths as much ferric as ferrous oxide, while in the sediments there is about one and three-fourths times as much.

Corresponding ratios for the two chief groups of sediments are as follows:

Shales, $FeO:Fe_2O_3::2.46:4.03$, or about 1:1.64.
Sandstones, $FeO:Fe_2O_3::0.57:1.24$, or about 1:2.17.

Thus, as stated above, the magnitude, but not the sign, of the results for the sediments will vary with the weights given to shales and to sandstones. But even were the figures for shales taken alone, throwing out the sandstones entirely, it is evident that the ratio of ferric to ferrous oxide is double that found in the older crust.

As the shales, sandstones, and limestones represent, in altered form, the materials of the old crust, and as the two latter show, as compared with the old crust, a decrease of iron, while the shale shows no increase, it is clear that, if the analyses are to be used as a basis of calculation, allowance must be made for concentration of iron in ores and other highly ferruginous rocks. Moreover, in the change from old crust to silicious sediments, there must be a loss of calcium and magnesium to form limestones, and of sodium held in sea-water, while there is a gain of carbon dioxide and water.

In view of these facts, it is probable that 4 per cent. is a moderate estimate of the total oxidized iron of sediments, excluding limestones, and it is assumed that the ratio between ferrous and ferric oxides is that above derived from Stokes's analyses.

To determine the amount of oxygen combined with iron in the sediments, Joly's[1] estimate of the mass of silicious sediments, 64×10^{16} tons (of 2,240 pounds) is taken as the amount of shales, sandstones, and ferruginous rocks.

This gives 256×10^{14} tons of iron, which, occurring as Fe_2O_3 and FeO in the ratio 2.64:1.52, requires 96×10^{14} tons of oxygen. The same amount of iron occurring as Fe_2O_3 and FeO in the ratio of the old crust, 2.63:3.52, requires $8{,}765\times10^{12}$ tons of oxygen.

The difference between these two amounts, 835×10^{12} tons, is a measure of the quantity of oxygen taken from the atmosphere and fixed in the silicious sedimentary rocks through the agency of iron. Calculating, from Woodward's[2] statement as to the mass of the atmosphere, the total amount of oxygen as $1{,}213\times10^{12}$ tons, the quantity abstracted by iron is equal to 68.8 per cent. of that now present in the atmosphere.

While this estimate manifestly can lay no claim to even approximate accuracy, it suffices to show that the abstraction of oxygen by iron is a factor that cannot be disregarded in any attempt to work out the geological history of the atmosphere.

[1] *Scientific Transactions of the Royal Dublin Society*, Vol. VII, Ser. II, p. 46.

[2] *Bulletin No. 78*, U. S. Geological Survey, p. 34.

THE FAUNA OF THE CLIFFWOOD (N. J.) CLAYS[1]

STUART WELLER
The University of Chicago

Several papers have recently appeared in which the beds at Cliffwood Point on the south shore of Raritan Bay, New Jersey, have been discussed, and some difference of opinion as to their correlation has been expressed.[2] For the most part the discussion has been based upon the evidence as shown by the fossil flora, although mention of marine invertebrate fossils has been made in several of the papers. During the past two field seasons extensive collections of these invertebrates have been made by the writer from the locality in question, as well as from the clay pits in the neighboring region which have been opened in the same beds. At Cliffwood Point the fossils were collected from smooth, concretionary nodules, which occur in great numbers along the beach at low tide. Although most of the fossils were collected from nodules not *in s tu* a few similar nodules carrying the same fossils have been found imbedded in the clay, and no doubt can be entertained as to the original source of all the nodules being from the clay at the locality in question, from a horizon near or somewhat below high-water level. Their occurrence in essentially the same beds, or even in beds a little lower

[1] Published by permission of the state geologist of New Jersey.

[2] Arthur Hollick, "The Cretaceous Clay Marl Exposure at Cliffwood, N. J.," *Transactions of the New York Academy of Sciences*, Vol. XVI, pp. 124–36; Edward W. Berry, "The Flora of the Matawan Formation (Crosswick's Clays), *Bulletin of the New York Botanical Garden*, Vol. III, No. 9, 45–103; Edward W. Berry, "New Species of Plants from the Matawan Formation," *American Naturalist*, Vol. XXXVII, pp. 677–84; G. N. Knapp, "The Cliffwood Clays and the Matawan," *American Geologist*, Vol. XXXIII, pp. 23–27; Edward W. Berry, "The Cretaceous Exposure near Cliffwood, N. J.," *ibid.*, Vol. XXXIV, pp. 253–60; W. B. Clark, "The Matawan Formation of Maryland, Delaware, and New Jersey, and its Relations to Overlying and Underlying Formations, *American Journal of Science*, 4th Ser., Vol. XVIII, pp. 435–40; Edward W. Berry, "Additions to the Flora of the Matawan Formation," *Bulletin of the Torrey Botanical Club*, Vol. XXXI, pp. 67–82; Edward W. Berry, "Additions to the Fossil Flora from Cliffwood, New Jersey," *ibid.*, Vol. XXXII, pp. 43–48.

than those containing the plants described by Ho lick and Berry, may be safely assumed.

One of the most notable features of the fauna from these Cliffwood nodules is the great number of Crustacean remains. Nearly every one of the concretions, when broken, yields the remains, more or less fragmentary and crushed, of one of these creatures; indeed, a crab of some sort seems to have been the nucleus around which every one of these concretionary nodules in the clay has been formed. In addition to the crustacean remains, which seem to represent several species, the nodules have yielded a goodly number of mollusca, and the following species have been more or less satisfactorily determined:

PELECYPODA

1. **Ostrea** sp. undet. At least two species of oysters have been recognized in the Cliffwood fauna, neither one of which can be identified with any of the species occurring in the other Cretaceous beds of New Jersey.
2. **Anomia tellinoides** Mort.
3. **Amusium** sp. undet. This species is much larger than either of the members of the genus previously recorded from New Jersey, and it seems to be undescribed. It resembles in general form some specimens of *Camptonectes burlingtonensis* Gabb, but lacks the distinctive ornamentation of that shell.
4. **Mytilus oblivius** Whitf. Although this shell attains a larger size in the Cliffwood clays than any specimens observed from the Wenonah sand, the only other horizon where it has been observed, there seems to be no reason for considering the Cliffwood specimens as specifically distinct.
5. **Modiola** sp. undet. A single imperfect specimen may be referred here. It somewhat resembles the shell described from the West as *Volsella attenuata* M. & H.
6. **Pteria petrosa** Con. Whitfield saw but one imperfect specimen of this species during the preparation of his monograph of the New Jersey Cretaceous pelecypods,[1] and Conrad in his original description mentions seeing but a single specimen from the Delaware and Chesapeake Canal. In the Cliffwood fauna it is one

[1] *Paleontology of New Jersey*, Vol. I, p. 69; also *Monograph*, U. S. Geological Survey, Vol. IX, p. 69.

of the most common forms, and has been seen elsewhere in New Jersey only in the Wenonah sand. It seems to be indistinguishable from *P. linguiformis* E. & S., from the West.

7. **Inoceramus sagensis** Owen. Elsewhere in New Jersey this species occurs most commonly in the Merchantvillle clay marl.
8. **Nemodon brevifrons** Con. This species has been recognized elsewhere in the New Jersey faunas only in the Woodbury clay near Haddonfield and in the same formation in Monmouth County.
9. **Breviarca** sp. undet. This is probably an undescribed form; it is closely allied to, if not identical with, a species occurring in the Woodbury clay fauna of Monmouth County.
10. **Nucula slackiana** Gabb. Specimens of this species in the Cliffwood fauna are indistinguishable from specimens from the Woodbury clay.
11. **Nucula** sp. undet. This species seems to be undescribed, but it is identical with a form which occurs in the Wenonah sand fauna.
12. **Nuculana protexta** (Gabb)? Specimens which seem to be referable to this species are rather common in the fauna.
13. **Nuculana** sp. undet. The specimens here indicated are possibly but a form of the last.
14. **Lucina cretacea** Con. This species, which occurs so abundantly in the Woodbury clay, is one of the rarest forms in the Cliffwood fauna.
15. **Cardium ripleyanum** Con.? Several specimens of a small *Cardium* have been referred questionably to this species, they being too imperfect for certain identification.
16. **Isocardia cliffwoodensis** n. sp. (Figs. 1–3). This is one of the most characteristic, though not the most common, species of

FIG. 1

FIG. 2

FIG. 3

the Cliffwood fauna, being present in every locality where the fauna has been observed. A similar, if not identical, species occurs in the Wenonah sand fauna.

17. **Dosinia gabbi** Whitf. Several fragmentary specimens seem to be referable to this species, although they are too imperfect for certain identification.
18. **Tellina equilateralis** M. & H.? Several incomplete specimens seem to resemble this species originally described from the Fox Hills beds of the West. The specimens are too imperfect for certain identification.
19. **Veleda lintea** (Con.). This is a rather variable shell, but specimens from the Cliffwood clays are indistinguishable from examples occurring in the Wenonah sand, where the species most commonly occurs.
20. **Veleda transversa** Whitf.? Among the specimens of *Veleda* in the Cliffwood fauna several specimens seem to approach this species in form, and have been so identified provisionally.
21. **Pholadomya occidentalis** Mort. A single incomplete impression of a large shell seems to represent this species. Eleswhere it seems to be quite closely confined to the Merchantville clay marl.
22. **Corbula** sp. undet. The internal casts of this species are rather abundant, but it is difficult to identify them with shells which have been described from external characters. The species seems to resemble the shell illustrated by Whitfield under the name *C. joulkei* Lea, which is in reality not that species, but *C. bisulcata* Con.

GASTROPODA

23. **Pyropsis** sp. undet. This shell resembles *P. naticoides* Whitf., and it is possible that it should be so identified.
24. **Pyrifusus erraticus** Whitf. This species is represented by two specimens. It was originally described from a nodule said to have been collected at Cliffwood, N. J.
25. **Volutimorpha gabbi** Whitf.? This species is represented by a single specimen which most closely resembles Whitfield's[1] *fig. 4*, Plate VIII, referred provisionally to *V. gabbi* Whitf. The Cliffwood specimen is a nearly smooth internal cast and does not show the external markings of the shell.

[1] *Paleontology of New Jersey*, Vol. II; also *Monograph* U. S. Geological Survey, Vol. XVIII.

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12. **Nuculana protexta** (Gabb)? Specimens which seem to be referable to this species are rather common in the fauna.
13. **Nuculana** sp. undet. The specimens here indicated are possibly but a form of the last.
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FIG. 1

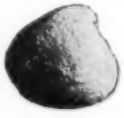

FIG. 2

FIG. 3

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[1] *Paleontology of New Jersey*, Vol. II; also *Monograph* U. S. Geological Survey, Vol. XVIII.

26. **Scalaria** sp. undet. A fragmentary specimen of a member of this genus has been observed. It is too imperfect for identification.

27. **Turritella encrinoides** Mort.? Fragments of the internal casts, as well as impressions of the external markings, of a *Turritella* occur in the Cliffwood fauna, which seem to be referable to this species.

CEPHALOPODA

28. **Placenticeras placenta** De Kay. A single fragment of the cast of the chamber of habitation of a large ammonite resembles in all respects similar specimens known to belong to *P. placenta*, and little doubt can be entertained as to the correctness of this identification of the Cliffwood specimen.

29. **Baculites** sp. undet. A fragment of the cast of the chamber of habitation may certainly be referred to this genus. The specific determination cannot be satisfactorily made. It may belong to the common *B. ovatus* of the New Jersey Cretaceous beds, but it seems to possess stronger, oblique, annular ridges than is usual in that species.

CRUSTACEA

30. **Tetracarcinus subquadratus** n. gen. and sp. (Figs. 4–6). Several species of crustaceans, all of them probably undescribed, are present in the Cliffwood fauna. A single one of these forms, however, may be considered in the present connection, for the

FIG. 4

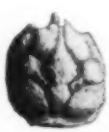

FIG. 5

FIG 6

reason that it is also a common form in the fauna of the Woodbury clay. It has not been possible to place this little crab in any of the described genera, and therefore it may be called *Tetracarcinus* on account of its subquadrangular form, with the specific name *subquadratus*. The dimensions of an average specimen are: length of carapace, 14.5^{mm}; breadth, 14^{mm}; greatest con-

vexity, 5^{mm}. The regions of the carapace are clearly marked by more or less deeply impressed furrows, as shown in the accompanying illustrations. This is one of the common forms in the Cliffwood fauna, and is the only crustacean which has been observed in the fauna of the Woodbury clay.

A sandstone mass was collected on the beach at Cliffwood, eighteen inches in length by twelve inches in breadth and perhaps three inches thick, completely filled with fossils. This mass of sandstone was not *in situ*, and, being different in its lithologic characters from any material imbedded in the clay at this point, it may have been transported to this locality from elsewhere. It is, however, somewhat similar in its lithologic characters to certain sandy, fossiliferous nodules occurring in the clay at the pits of the Cliffwood Brick Company, a little over a mile distant on Whale Creek. The fauna yielded by this sandstone undoubtedly indicates its Cliffwood age, although several species occur which have not been observed elsewhere. The species of fossils identified are as follows:

PELECYPODA

1. **Breviarca** sp. undet. This is apparently the same species as that noted from the fauna of the crustacean nodules.
2. **Trigonarca** n. sp.? This is one of the common species of the fauna, and is apparently undescribed. It has the form of a small *Idonearca*, but is less convex than most species of that genus and has a different hinge structure.
3. **Trigonarca** n. sp.? This is a larger species than the last, and the hinge bears a much larger number of teeth. Neither of the species has been observed elsewhere.
4. **Nuculana protexta** (Gabb)? The specimens of this species are poorly preserved, but they seem to be specifically identical with those from the crustacean nodules which have been identified as *N. protexta*.
5. **Yoldia** cf. **evansi** M. & H. This is a rather common species in the fauna, and is closely allied to, if not identical with, *Y. evansi* from the Fox Hills beds of the West.
6. **Cardium** sp. undet. This species can be identified with none

of the recognized forms from New Jersey, and is probably an undescribed species.

7. **Isocardia cliffwoodensis** n. sp. This is the same form that occurs in the fauna of the crustacean nodules.
8. **Veleda lintea** Con. This is the most abundant species in the fauna.
9. **Corbula** sp. undet. Two or three unidentified species, and possibly undescribed, seem to be referable to the genus *Corbula*.

GASTROPODA

10. **Pyrifusus** sp. undet. This is apparently an undescribed species, and has not been observed elsewhere.
11. **Volutomorpha** sp. undet. This also seems to be an undescribed form which has not been observed elsewhere.
12. **Gyrodes** sp. undet. This is a small species, which apparently cannot be referred to any of the recognized New Jersey species, and may be new.
13. **Scalaria** sp. undet.
14. **Turritella** sp. undet.

At Geldhaus' clay pits, a little over a mile west of Cliffwood Point, on Whale Creek, crustacea bearing nodules similar to those collected on the beach at Cliffwood, occur *in situ* in the clay. Besides the numerous imperfect crustacean remains, the following species have been recognized at this locality:

PELECYPODA

1. **Pteria petrosa** Con.
2. **Nuculana protexta** Gabb.
3. **Lucina cretacea** Con.
4. **Isocardia cliffwoodensis** n. sp.
4. **Veleda lintea** (Con.)
6. **Corbula** sp. undet.

In the Cliffwood Brick Company's south pits, at the crossing of the New York and Long Branch R. R. over Whale Creek, numerous, sandy, abundantly fossiliferous nodules were obtained *in situ*. In the fauna of these nodules the following species have been recognized:

PELECYPODA

1. **Ostrea** sp. undet. A small undetermined species.
2. **Amusium** sp. undet. This is the same species noted in the fauna of the crustacean nodules from the beach at Cliffwood.
3. **Breviarca** sp. undet. This is the same species as that occurring in the crustacean nodules at Cliffwood Point.
4. **Nuculana protexta** (Gabb)?
5. **Yoldia** cf. **evansi** M. & H.
6. **Cardium** sp. undet. This is the same species noted from the sandstone slab collected at Cliffwood.
7. **Cymella bella** Con. This species is represented by several specimens. Elsewhere it occurs rarely in the Merchantville, more commonly in the Woodbury, and most abundantly in the Wenonah formation.
8. **Isocardia cliffwoodensis** n. sp.
9. **Cyprimeria** sp. undet. This is a small species which cannot be identified with other New Jersey forms, but it is most like a species in the Woodbury clay, where he genus occurs most abundantly. A form apparently identical with this Cliffwood shell occurs rarely in the Wenonah fauna.
10. **Tellina** sp. undet. Several specimens of a shell apparently referable to this genus are present in the fauna. They seem to belong to an undescribed species.
11. **Linearia metastriata** Con. This species rarely occurs in the Merchantville clay, it is abundant in the Woodbury clay near Haddonfield, and is one of the most abundant species of the Wenonah sand.
12. **Veleda lintea** (Con.). This is the most abundant species in the fauna.
13. **Pholadomya occidentalis** Mort. Several fragments which seem to represent this species have been observed.
14. **Corbula** sp. undet. A species of this genus, apparently undescribed, is represented by several specimens.
15. **Leptosolen biplicata** Con. This species has been recognized elsewhere in the Merchantville clay, the Woodbury clay, and the Wenonah sand, it being most common in the last of these formations.

GASTROPODA

16. **Pyrifusus** sp. undet. A single specimen of an undescribed shell is apparently referable to this genus.
17. **Gyrodes** sp. undet. Fragmentary specimens of a small species of this genus are present in the fauna. They are apparently different from any of the recognized New Jersey forms.
18. **Turritella encrinoides** Mort.? Fragmentary specimens of a species of *Turritella*, probably belonging to this species, occur in this fauna.

Several nodules, not *in situ*, were collected in the same pits of the Cliffwood Brick Company as the fauna last recorded. They undoubtedly had their origin in these same clay beds, and the following species of fossils have been recognized in them:

PELECYPODA

1. **Ostrea** sp. undet. One of the same species noted in the fauna of the crustacean nodules at Cliffwood Point.
2. **Anomia tellinoides** Mort.
3. **Amusium** sp. undet. This is the same as the species recorded in the Cliffwood fauna.
4. **Pteria petrosa** Con.
5. **Inoceramus sagensis** Owen.
6. **Breviarca** sp. undet. This is the same form as that recorded from the crustacean nodules at Cliffwood Point.
7. **Nuculana protexta** (Gabb)?
8. **Cardium** sp. undet.
9. **Isocardia cliffwoodensis** n. sp.
10. **Veleda lintea** (Con.).
11. **Corbula** sp. undet. This is the same species as that numbered 22 in the list of species from the crustacean nodules collected at Cliffwood Point.
12. **Corbula**? sp. undet.

GASTROPODA

13. **Pyrifusus** sp. undet.

CRUSTACEA

14. **Tetracarcinus subquadratus** n. gen. and sp.

The data recorded in the preceding lists of fossils are assembled in the following table in order that they may be more readily analyzed.

A separate column is allotted to each of the preceding groups of species, numbered as follows: (1) nodules collected on the beach at low tide at Cliffwood point; (2) sandstone mass from beach at Cliffwood Point; (3) Geldhaus' clay bank; (4) Cliffwood Brick Company's south pits, nodules *in situ;* (5) Cliffwood Brick Company's south pits, ferruginous nodules not *in situ.* The last three columns are assigned to the three higher formations as follows: Merchantville clay (Mv), Woodbury clay (Wb), and Wenonah sand (W); and the occurrence of the Cliffwood species in these formations is noted.

	1	2	3	4	5	Mv	Wb	W
PELECYPODA—								
1. *Ostrea* sp. 1	x	—	—	—	x	—	—	x
2. *Ostrea* sp. 2	x	—	—	—	—	—	—	—
3. *Anomia tellinoides* Mort	x	—	—	—	x	x	—	x
4. *Amusium* sp. undet	x	—	—	x	x	—	—	—
5. *Mytilus oblivius* Whitf	x	—	—	—	—	—	—	x
6. *Modiola* sp. undet	x	—	—	—	—	—	—	—
7. *Pteria petrosa* Con	x	—	x	—	x	—	—	x
8. *Inoceramus sagensis* Owen	x	—	—	—	x	x	—	—
9. *Nemodon brevifrons* Con	x	—	—	—	—	—	x	—
10. *Breviarca* sp. undet	x	x	—	x	x	—	x	—
11. *Trigonarca* sp. 1	—	x	—	—	—	—	—	—
12. *Trigonarca* sp. 2	—	x	—	—	—	—	—	—
13. *Nuculana slackiana* Gabb	x	—	—	—	—	—	x	—
14. *Nucula* sp. undet	x	—	—	—	—	—	—	x
15. *Nuculana protexta* (Gabb)?	x	x	x	x	x	—	—	—
16. *Yoldia* cf. *evansi* M. & H	—	x	—	x	—	—	—	—
17. *Lucina cretacea* Con	x	—	x	—	—	—	x	—
18. *Cardium* sp. 1	x	—	—	—	x	—	—	—
19. *Cardium* sp. 2	—	x	—	x	—	—	—	—
20. *Cymella bella* Con	—	—	—	x	—	x	x	x
21. *Isocardia cliffwoodensis* n. sp	x	x	x	x	x	—	—	x
22. *Cyprimeria* sp. undet	—	—	—	x	—	—	—	x
23. *Dosinia gabbi* Whitf.?	x	—	—	—	—	—	—	—
24. *Tellina equilateralis* M. & H.?	x	—	—	—	—	—	—	—
25. *Tellina* sp. undet	—	—	—	x	—	—	—	—
26. *Linearia metastriata* Con	—	—	—	x	—	x	x	x
27. *Veleda lintea* (Con.)	x	x	x	x	x	x	x	x
28. *Pholadomya occidentalis* Mort	x	—	—	x	—	x	—	x
29. *Corbula* sp. undet	x	—	—	—	x	x	—	—
30. *Leptosolen biplicata* Con	—	—	—	x	—	x	x	x
GASTROPODA—								
31. *Pyropsis naticoides* Whitf.?	x	—	—	—	—	—	—	—
32. *Pyrifusus erraticus* Whitf	x	—	—	—	—	—	—	—
33. *Pyrifusus* sp. undet	—	x	—	—	—	—	—	—
34. *Pyrifusus* sp. undet	—	—	—	x	—	—	—	—
35. *Pyrifusus* sp. undet	—	—	—	—	x	—	—	—
36. *Volutomorpha gabbi* Whitf.?	x	—	—	—	—	—	—	—
37. *Volutomorpha* sp. undet	—	x	—	—	—	—	—	—
38. *Gyrodes* sp. undet	—	x	—	x	—	—	—	—
39. *Scalaria* sp. undet	x	—	—	—	—	—	—	—
40. *Scalaria* sp. undet	—	x	—	—	—	—	—	—
41. *Turritella encrinoides* Mort.?	x	—	—	x	—	x	x	x
CEPHALOPODA—								
42. *Placenticeras placenta* De Kay	x	—	—	—	—	x	x	x
43. *Baculites* sp. undet	x	—	—	—	—	—	—	—
CRUSTACEA—								
44. *Tetracarcinus subquadratus* n. sp	x	—	—	—	x	—	x	—
						10	11	14

A careful analysis of this fauna of the Cliffwood clays brings clearly to view several important facts. In the first place, the large number of species which are common to the fauna, and to one or more of the faunas of the formations above, emphasizes the close relationship between the Cliffwood fauna and these higher faunas. This relationship is, indeed, so close that they constitute essentially but different faunules of one large fauna. There is no sharper distinction between the fauna of the Cliffwood clays and the Merchantville clay than there is between the Merchantville and the Woodbury clays. However, the Cliffwood fauna does possess characteristics which distinguish it somewhat sharply from the Merchantville fauna, among which may be mentioned the abundance of the species *Pteria petrosa* and *Isocardia cliffwoodensis*, which have nowhere yet been recognized in the Merchantville, and the especial abundance, in some cases at least, of *Veleda lintea*, which is sometimes present, although always rare in the Merchantville. None of the crustaceans which are so abundant in the Cliffwood fauna have been recognized in the Merchantville, although claws and other disarticulated joints of crustacean appendages are not uncommon in the higher fauna at some localities. The distinction between these two faunas is not alone emphasized by the species present in the Cliffwood and absent from the Merchantville, but also by the genera and species which are absent from the Cliffwood and almost universally present in the Merchantville fauna. Among such genera may be mentioned *Idonearca*, *Trigonia*, *Panopea*, *Axinea*, and *Leiopistha*.

On making a careful comparison between the Cliffwood fauna and that of the Woodbury clay, the formation immediately above the Merchantville, a much greater resemblance is noted than between the Cliffwood and the Merchantville; the same Merchantville genera mentioned above as being conspicuously absent from the Cliffwood fauna are also conspicuous for their absence from the Woodbury. Furthermore, several forms are common to the Cliffwood and the Woodbury faunas which have not been observed in the intervening formation, among which may be mentioned *Breviarca*, *Lucina cretacea*, and the little crustacean here called *Tetracarcinus subquadratus*. In making this comparison, however, it must not be overlooked that some of the most characteristic Cliffwood species, as *Isocardia*

cliffwoodensis and *Pteria petrosa*, have nowhere been observed in the Woodbury fauna.

It is unnecessary to make comparison between the Cliffwood and the Marshalltown faunas, as there is scarcely anything in common between them; but with the fauna of the Wenonah sand the Cliffwood fauna has more in common even than with that of the Woodbury clay. Among the species listed in the table given above, it will be seen that fourteen species are recorded as being common to the Cliffwood and the Wenonah, eleven to the Cliffwood and the Woodbury, and only ten to the Cliffwood and the Merchantville. These numbers do not fully express the relative proximity of relationship between these several faunas, although they do partially, because no account is taken of the relative abundance of the forms noted. As a matter of fact, when the abundance of the different species in the different faunas is taken into account, the similarity of the Cliffwood and Wenonah faunas is accentuated, while that between the Cliffwood and the Merchantville is diminished. Aside from the crustaceans of the Cliffwood fauna, the two species *Pteria petrosa* and *Isocardia cliffwoodensis* are perhaps the most characteristic forms, and both of these occur in the Wenonah fauna. *Veleda lintea* is another conspicuous Cliffwood species which occurs more frequently in the Wenonah sand than in any other of the New Jersey Cretaceous formations.

It is believed that these comparisons which have been instituted make clear the fact that, however much or however little the Cliffwood fauna has in common with the faunas of the higher formations, it does have a unity of its own. Although many of the species occur also in other horizons, the whole assemblage of species, considered as a faunule, possesses characteristics which serve to distinguish it from any of the other faunules with which it has been compared.

The geographic distribution of this Cliffwood fauna differs notably from that of the Merchantville, it being limited, so far as now known, to a small area between Cliffwood Point and the head of Cheesquake Creek. The distribution of the Merchantville fauna is entirely across the state, from the south shore of Raritan Bay to the shores of Delaware Bay; throughout its entire extent it is remarkably constant in its characters, and the Merchantville beds are everywhere marked

by constant lithologic characters, yielding fossils, usually in abundance, wherever they are well exposed. There is scarcely a formation in the entire Cretaceous series of New Jersey which is more sharply marked, both lithologically and faunally, than the Merchantville clay. The base of the formation constitutes an easily recognizable and perfectly natural geologic horizon, the beds below being characterized by the great heterogeneity of their lithologic characters, while the beds above are just as strongly characterized by the constancy of their lithologic characters.

The heterogeneous assemblage of sands and clays beneath the Merchantville have been called the Raritan formation, and the fossiliferous clays at Cliffwood which are interbedded with sands and are lithologically allied to the subjacent beds, must certainly be considered as a lens-like body included in the Raritan. The Raritan beds for the most part give evidence of a non-marine origin, but there must have been marine conditions present along the Atlantic border at no great distance during the entire period of their deposition. The non-marine, perhaps estuarian conditions of Raritan time were supplanted in Merchantville time by more uniform marine conditions, but, previous to the initiation of marine conditions in the area entirely across New Jersey, we find evidence here in the Cliffwood clays of a slight transgression of the sea from the direction where marine conditions had continuously existed, and the occupation of a small area where non-marine sediments had previously been deposited.

This occurrence at Cliffwood of marine fossils in the Raritan is not the only case of the kind in New Jersey, although it is the most notable one. Whitfield[1] mentions the occurrence of *Turritella encrinoides*, a not uncommon species in the Cliffwood beds as well as in some of the higher formations, in the clays at Sayersville, which are near the very base of the Raritan; and the slab mentioned by him, bearing many examples of this species, is now preserved in the collections of the Geological Survey of New Jersey. Other specimens of marine fossils from near the same locality have recently been acquired by Mr. J. M. Manley, of New Brunswick, N. J. It is altogether possible, and indeed most probable, that faunas more or less closely allied to those of the higher formations were living, throughout the

[1] *Paleontology of New Jersey*, Vol. II, p. 144.

entire period of deposition of the Raritan beds, at no great distance from the present shores of Raritan Bay; and, if that were the case, it is not at all surprising that there should be occasional transgressions of marine conditions within the area where non-marine sedimentation was usually in progress, with the consequent deposition of marine beds with marine fossils.

THE HALLOPUS, BAPTANODON, AND ATLANTOSAURUS BEDS OF MARSH

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HALLOPUS BEDS

In the *American Journal of Science* for October, 1891, Professor O. C. Marsh proposed the name "Hallopus beds" for a somewhat indeterminate horizon of vertebrate fossils, as follows:

> Near the base of the Jurassic a new horizon may now be defined as the Hallopus beds, as here alone remains of the remarkable reptile named by the author *Hallopus victor* have been found. Another diminutive dinosaur, *Nanosaurus*, occurs in the same strata. The horizon is believed to be lower than the Baptanodon beds, though the two have not been found together. The Hallopus beds now known are in Colorado, below the Atlantosaurus beds, but quite distinct from them.
>
> The Baptanodon beds have been found in many localities everywhere beneath the Atlantosaurus beds, and having below them, at various localities, a series of red beds, which may, perhaps, contain the Hallopus horizon, but are generally regarded as Triassic.

This reference of Marsh to a vertebrate horizon below the marine Jurassic of the Rocky Mountain region has been wholly overlooked or disregarded by subsequent writers, the fauna itself having been referred to the "Upper Jura." I am now in a position, I believe, to show that the horizon is a distinct one, and that it belongs, not to the Lower Jurassic, but to the Upper Triassic. I, furthermore, believe that the horizon will eventually be found to be widely fossiliferous in the Rocky Mountain region.

Although I cannot be entirely sure, after so long an interval, it is my recollection that the type specimen of *Hallopus victor* was discovered by Mr. M. P. Felch in August, 1877, in Garden Park, near Cañon City, Colo., a few weeks before the time of my first visit to that since famous locality. The precise spot whence the specimen came was pointed out to me, the base of an escarpment of red sandstone, whither the specimen had fallen from the overhanging

cliff. Its precise horizon in the cliff was never ascertained, though the block of red sandstone in which the fossil was inclosed left no doubt as to its derivation. This peculiar character of the matrix, so different from anything found in the Atlantosaurus beds, has been mentioned by Marsh, though he never gave definite information as to the location of the discovery.

Of the other specimen, that upon which was based the genus *Nanosaurus* originally, I have no clear recollection, though I have no doubt it was from the same spot and horizon as the type of *Hallopus*. The fact that only one-half of the split slab was obtained, as mentioned by Marsh, indicates that the specimen was not discovered *in situ*. At the time of my first visit to Cañon City, in September or early October of 1877, I searched diligently in the adjacent red sandstones for the Hallopus horizon, but without success.

In July of the past year Mr. W. H. Reed, of the University of Wyoming, informed me that he had, some years previously, discovered vertebrate fossils in the red sandstones of the Red Mountain region, south of Laramie City, Wyo., and very kindly took me to the place of his discovery. We found there numerous fragments of bones, scattered along a thin stratum, near the top of the red beds. The marine Jurassic is here wanting, as at Cañon City, the sandstone of the Morrison or Atlantosaurus beds overlying the red beds without marked unconformity. The lower members of these beds consist of a grayish or yellowish sandstone, and are unfossiliferous, the first vertebrate fossils occurring seventy-five feet or more above the red-beds horizon. Because of an apparent absence of distinctive Triassic fossils among those secured in the short time at our disposal, I was somewhat inclined at the time to refer this horizon to the Lower Jurassic, or possibly as a fresh-water equivalent of the Baptanodon beds; the more so from the fact that the crocodile remains obtained seemed to approach the mesosuchian type.

At my request, however, Mr. Reed spent some time later in a further examination of the deposits, the results of which he has recently sent me. Among the material which he obtained there are very characteristic labyrinthodont plates and vertebræ, proving conclusively the Triassic age of the deposits. Furthermore, the occurrence of the bones in the red sandstone stratigraphically quite

conformable with, and undifferentiated from, the red beds below, seems to render any other disposition of the horizon out of the question.

The differences of these fossils from those obtained in the Lander region from an horizon fully two hundred and fifty feet below the top of the beds, are such that their contemporaneity of deposition is very improbable. These differences are especially noticeable, *inter alia*, in the apparent absence of the teeth so characteristic of those and many other American Triassic deposits—teeth usually referred to a somewhat problematical genus of dinosaurs, called *Paleoctonus*. These teeth, however, are of several types, and it is very probable that none of them belong with dinosaurs. Indeed, the association of one of the forms with the genus *Dolichobrachium* Williston seems now assured. This genus, however, seems closely allied to, possibly identical with, the genus *Theriodesmus* from the Karoo beds of South Africa—a problematical genus whose relationships are yet quite unknown. So different, indeed, is the genus, or at least *Dolichobrachium*, that it must be ascribed to a distinct group, perhaps order of reptiles. It is interesting, also, to observe that a recent letter from Dr. Broom confirms the reference of the Anomodont-like reptiles described by me to the true dicynodonts.

Nothing of the kind has been discovered in the Connecticut valley Trias, while the occurrence of true dinosaurs in those beds, as also pseudosuchian crocodiles, none of which have been certainly found in the Triassic deposits of the West, save the Hallopus beds, would indicate that the most eastern deposits are of a different, perhaps later, age. I am much inclined to believe that the Popo Agie beds, which may be contemporaneous with those yielding vertebrate fossils in Utah, Arizona, New Mexico, and Texas, are of early Keuper age, while the Connecticut valley, the Red Mountain, and Hallopus beds of southern Colorado are later in time.

Taking all the facts into consideration, I believe that the horizon of the Red Mountain beds is nearly or quite identical with that of the Hallopus beds of Cañon City.

That the Hallopus beds of Colorado are of Lower Jurassic age there is not a particle of evidence, unless it be in the ornithopodous character of the dinosaur *Nanosaurus*, a type never before found so low, though confidently expected from the Trias. The primitive

characters of *Hallopus* are shown especially in the sacrum. The type specimen, as Marsh has said, came from an horizon far below the lowermost of those yielding sauropodous remains. Hatcher has said that "no fossils have been obtained from the Red Beds of Garden Park"—an error.

BAPTANODON BEDS

From the Baptanodon beds of Wyoming three genera and eight species of vertebrates have been described: *Baptanodon discus* Marsh, *B. natans* Marsh, *B. marshi* Knight, *Pantosaurus striatus* Marsh, *Megalneusaurus rex* Knight, *Cimoliasaurus laramiensis* Knight, *Plesiosaurus shirleyensis* Knight, and *Diplosaurus nanus* Marsh. Of these I am not satisfied of the distinction between *Pantosaurus striatus* and *Plesiosaurus shirleyensis*.

On the evidence which seemed to be presented by *Baptanodon*, Hatcher was inclined to refer these beds to the Middle Jurassic: "The vertebrates of these marine beds point to a somewhat greater antiquity than do the invertebrates, for *Baptanodon*, the most abundant and best-known form, has its nearest ally in the *Ophthalmosaurus* of Europe;"[1] from which, as he rightfully says, it is scarcely distinguishable generically. While *Ophthalmosaurus* is typically[2] from the Middle Jurassic, another species[3] has been described from the Cambridge Greensand (Upper Cretaceous). While it is very possible, indeed not improbable, that these two species are not congeneric, it is also apparently quite true that *Baptanodon* seems to be as closely allied to the Cretaceous as to the Jurassic species. Indeed, in speaking of the Cretaceous form, Lydekker says: "This species may belong in *Baptanodon*." It is therefore evident that, so far as our knowledge yet goes, *Baptanodon* is worthless as a Leitfossil.

In a later, posthumous[4], paper Hatcher has said: "that these beds are of Upper Jurassic has not been questioned, and is abundantly confirmed by both their vertebrate and invertebrate faunas;" from which it is evident that he later placed no value on the relationships

[1] *Memoirs of the Carnegie Museum*, Vol. II (1903), p. 71.

[2] *O. icenicus* Seeley, *Quarterly Journal of the Geographical Society*, Vol. XXX (1874), p. 696.

[3] *O. cantabrigiensis* Lydekker, *ibid.*; *Geological Magazine* (3), Vol. V (1888), p. 310.

[4] *Proceedings of the American Philosophical Society*, Vol. XLIII (1904), p. 354.

of *Baptanodon* with the Jurassic *Ophthalmosaurus*, the only vertebrate which hitherto has been considered in their correlation.

I have studied all the types of the described species of plesiosaurs from these beds, and have examined all other material known from this horizon. These species all agree in having single-headed cervical ribs, and broad and short epipodials. From a somewhat careful study of the literature of English plesiosaurs, the earliest recorded occurrence of forms with single-headed cervical ribs that I can find is in the Oxford Clay, as is also the earliest of the short epipodial forms. One species described from the Baptanodon beds and referred to Cimoliasaurus (to which it probably does not belong) has three epipodial bones, as I am satisfied from an examination of the type specimen. The earliest European species having three epipodials, so far as I can ascertain, is from the Kimmeridge. All these characters are specializations, which became predominant in the Cretaceous, the elongated epipodials utterly disappearing. While species with two epipodials continue quite into the Fort Pierre Cretaceous, the length of the bones is materially lessened. The conclusion, therefore, to be derived from the plesiosaurs is that the beds are not older than the Kimmeridge. This conclusion is, of course, not decisive, as it may be that such specializations will yet be found in older forms in Europe, and since we can conceive of a more advanced evolution of the plesiosaurs in the western continent during these times.

The single crocodile described or named from these beds by Marsh presents no trustworthy evidence yet. Marsh referred the species to the genus *Diplosaurus*,[1] probably identical with the Wealden genus *Goniophilis*, and originally described from the Atlantosaurus beds. Should it prove to be rightly determined generically, it would point strongly to the Upper Jurassic, since no brevirostral crocodile is known from older rocks.

ATLANTOSAURUS BEDS

The age of the Atlantosaurus beds of Marsh, the Morrison beds of Cross, the Beulah shales of Jenney, the Como beds of Scott, has been variously discussed by Marsh, Osborn, Knight, Ward,

[1] *American Journal of Science*, Vol. L (November, 1895), p. 405. See also Marsh, "On the Geology of the Eastern Uintah Mountains," *ibid.*, Vol. I (March, 1871), Sep. p. 7.

Hatcher, and Darton. A résumé of this discussion will be found in Hatcher's recent paper on *Haplocanthosaurus*.[1] It is very evident that the final solution of the problem must be left chiefly to the vertebrate paleontologist, since the evidence presented by the invertebrates and the plants is not only scanty, but also, in the nature of things, insufficient. Aside from the discussions of Marsh, we are chiefly indebted to the late Mr. Hatcher for the presentation of the vertebrate evidence, and it is the views and statements presented by him that I wish to discuss here briefly. I will quote all of importance that he has to say:

> Marsh was wont to correlate the Atlantosaurus beds with the Wealden, which he regarded as of Upper Jurassic age. On just what evidence he relied for this correlation is not quite clear. Nor does a comparison of the dinosaurian faunas of these two horizons seem to warrant such correlation. While from the fragmentary nature of much of the material upon which the different genera and species are based it is clearly impossible to make satisfactory comparisons in many instances between the more closely related genera and species of American and European dinosaurs, nevertheless when comparisons of the faunas as a whole are instituted between the various American and European horizons, most striking and important resemblances and dissimilarities are at once apparent. Thus while in the Atlantosaurus beds the Sauropoda are the predominant forms both as regards size and the number of genera, species and individuals, in the Wealden they are almost entirely replaced by the Predentata and Theropoda. And the Iguanodontia, so abundant in the latter formation, are quite unknown in the former. It is not until we get down into the middle of the Oolite that we find a dinosaurian fauna comparable even with that of the Upper and Middle Atlantosaurus beds.[2]
>
> The dinosaurian fauna of the Wealden is certainly quite different and more modern than that of the Atlantosaurus beds. In the Wealden the Sauropod dinosaurs, which form such a conspicuous feature in the faunas of the Middle and Upper Jura, are on the wane, and that group of Predentate dinosaurs known as the Iguanodontia has attained unusual importance, assuming to a certain extent at least, the position formerly held by the Sauropoda. In the Altantosaurus beds, however, the Sauropoda predominate, and the Iguanodont group of the Predentata are represented by smaller and less specialized forms.[3]

From the foregoing it will be seen that Hatcher believed that the lower members of these beds are of real Jurassic age, that is below

[1] *Memoirs of the Carnegie Museum*, Vol. II (1903), p. 68.

[2] *Ibid.*, p. 72.

[3] *Proceedings of the American Philosophical Society*, Vol. XLIII (November, 1903), p. 353.

the Wealden, and, by inference, that they are even of Middle Jurassic age. Marsh consistently believed that they are equivalent to the Wealden of England, which he, however, in company with other good paleontologists, referred to the uppermost Jurassic rather than the lowermost Cretaceous.[1] These opinions from one who justly earned the distinction of being the chief paleontologic geologist among the students of vertebrate fossils in America are deserving of careful consideration. I must frankly say, however, that I am unable to draw any such conclusions as did Mr. Hatcher.

Cetiosaurus longus Owen is from the Great Oolite, or Middle Jura; *C. glymptonensis* Phillips, imperfectly known, is from the same horizon; while *C. brevis* Owen, also imperfectly known, is from the Wealden, but is referred by Seeley to *Ornithopsis*, by Lydekker to *Morosaurus*. *Ornithopsis* Seeley is from the Wealden; *O. humerocristatus* Hulke, from the Kimmeridge. Other, uncertain forms are from the Wealden of England. *Titanosaurus* is referred by Lydekker to probable Upper Greensand. Remains of the Sauropoda are spoken of as "frequent" in the Wealden, while from the Middle Jura only a few are known, and all these are of one, or at most two, species. I certainly cannot see what evidence these forms present that would lead one to say that the American forms are clearly Jurassic. The range of this suborder, so far as is known, is from the Middle Jurassic to the Upper Cretaceous, though there may be doubt as to the real age of the Indian form. Their known geographic distribution is Europe, India, Madagascar, Africa, South and North America—that is, over the whole world. The generalized characters presented by them are not at all sufficiently well understood to say off-hand that certain forms are older than others. No one has been better acquainted with the known dinosauria than the late Professor Marsh, and his opinions as to their relationships ought certainly to have weight, especially as he was inclined, perhaps, to exaggerate differences:

> Nearly all the American Sauropoda, indeed, show a higher degree of specialization than those of Europe, both in this feature [the relative length of the fore and

[1] *American Journal of Science*, Vol. I (1896), p. 234; Vol. II (1896), p. 438. "I have studied the Wealden at many localities in England and on the continent, and it contained a reptilian fauna similar to one I have found in the Rocky Mountains and regarded as Jurassic."

hind limbs] and in some other respects. Portions of one Wealden animal, referred by Mantell to *Pelorosaurus*, are certainly very similar to some of the smaller forms of *Morosaurus*, especially in the proportion of the fore and hind limbs, which are unusually short. This fact would at once distinguish them from *Pelorosaurus*, and, until the skull and more of the skeleton are known, they cannot be separated from *Morosaurus*.[1]

It is quite true that the Brachiosauridae of Riggs (*Brachiosaurus* Riggs and *Haplocanthosaurus* Hatcher) have a more generalized structure in this respect than has *Cetiosaurus* even, but we have no reason to assume that all the generalized forms died out with the advent of specialized ones, such as are most of the American Sauropoda. Nor do I think it quite certain that the Brachiosauridae are the most generalized, certainly not if the hypothesis that the Sauropoda have been derived from primitive ornithopoda is at all probable. Furthermore, the genus *Pleurocoelus*, originally described from the Potomac beds, has been recognized in the Atlantosaurus beds by Marsh, and later by Hatcher, and forms from the Wealden have been referred, provisionally at least, to the same genus.

For the most part, the carnivorous dinosaurs have little value in the correlation of the horizons. *Megalosaurus* is reported from Europe from the Lias to the Wealden. In America we have three or four genera of the Megalosauridae in the Atlantosaurus beds, *Creosaurus*, *Allosaurus*, *Antrodemus*, and *Ceratosaurus*, and the family survived to the Laramie Cretaceous. *Coelurus* was described from the Atlantosaurus beds, but is known to occur in the Potomac beds. In the Wealden of England *Aristosuchus* is very closely allied, indeed is supposed to be identical, and all the other genera referred to the Coeluridae are from the Wealden. In the extensive hollowness of the bones of the skeleton, *Coelurus* is not only the most specialized of dinosaurs, but of all vertebrate animals. The evidence then to be derived from the Theropoda is for the contemporaneity of the Wealden with the Atlantosaurus beds.

So far from the evidence of the Iguanodontia being against this correlation, I believe that it is decidedly for the identity of the two horizons. Iguanodonts are found in abundance in the Atlantosaurus beds, and of the largest size and high specialization. Speaking of them, Marsh has said:

[1] Dinosaurs of North America, p. 184.

> None of the [English] genera are known from America, but allied forms are not wanting. The nearest allied genera are apparently *Iguanodon* [Wealden] and *Camptosaurus*, for the large forms, and *Hypsilophodon* [Wealden] and *Laosaurus* for the smaller forms. . . . . Moreover we have in America a closely allied form [to *Hypsilophodon*] *Laosaurus*, of which several species are known.[1]

And, so far from the American forms being the most generalized, Lydekker says that *Hypsilophodon* is "the smallest and least specialized member of the family!" Perhaps this opinion is not decisive, but *Hypsilophodon* certainly cannot be called the most specialized. Lydekker even refers certain Kimmeridge and Wealden species to the American genus *Camptosaurus*.

Perhaps the best evidence we have for the Jurassic age of the American deposits is that of *Stegosaurus*, which is so closely allied to *Omosaurus* Owen from the Kimmeridge that Marsh believed the two genera to be identical. On the other hand, this type of the predentate dinosaurs seems to range from the Lower Lias in *Scelidosaurus*, to *Paleoscincus* from the Laramie, with four or five genera referred to the group from the Wealden. Its value, then, is slight.

Other evidence offered by the reptiles from the American beds is slight. A genus of crocodiles called by Marsh *Diplosaurus* seems to include *Hyposaurus vebbii* Cope from the Comanche Cretaceous of Kansas. Years ago Zittel referred both of these forms to the genus *Goniophilis* from evidence communicated by Professor Marsh, and *Goniophilis* is said to be "a genus very characteristic of the Wealden" (Lydekker). The recently published figure of the type specimen of *Diplosaurus*, when compared with figures of *Goniophilis*, shows a startling resemblance. Indeed, so far as I can learn, there are no brevirostral crocodiles known from below the Purbeck or lithographic slates. The evidence, then, of the crocodiles is decidedly for the uppermost Jurassic or Wealden age of the American beds.

Of the Chelonia the single species *Compsemys plicatulus* Cope (*Glutops ornatus* Marsh) is not at all decisive. If the species is correctly referred to *Compsemys*, all its related forms are of Cretaceous age. Nor is there any evidence to be obtained from the pterosaurs or birds. Of the mammals I will not venture to speak, save that I think that there are too few forms known from the Wealden to offer

[1] *American Journal of Science*, November, 1895, p. 411.

any basis of comparison. Of the fishes a few species of *Ceratodus* only are known, and inasmuch as this genus is supposed to range from the Trias to the present time, these species have no correlating value whatever.

To sum up: there is no valid vertebrate evidence pointing to an age greater than the Purbeck for the Atlantosaurus beds, and but very little for a greater age than that of the Wealden.

Unfortunately, in most of the discussions hitherto the Atlantosaurus beds have been considered as of some brief epoch. The faunas of the upper and lower parts have never been differentiated, save in some exceptional cases. Marsh, indeed, rarely ever gave any precise location for his type specimens, referring them simply to Wyoming, Colorado, etc. The term "Upper Jurassic" has been applied indiscriminately to the whole fauna, as it has, indeed, in the textbooks to the fauna of the Hallopus beds. Hatcher was the first to distinctly point out that the uppermost part of the beds might include a part of the Lower Cretaceous; and Darton has recently separated some of the upper part as Lower Cretaceous under the name of "Lakota beds."

I am strongly of the opinion that these deposits, nowhere, so far as known, exceeding a thickness of 500 feet, really represent various epochs between the Jurassic and the Upper Cretaceous, and that sooner or later we shall have evidence to distinguish the later from the earlier faunas.

A year or two ago Mr. N. H. Brown, of Lander, Wyo., sent some fish teeth to Mr. F. A. Lucas, of the National Museum, for determination. Mr. Lucas, after comparison with the type specimens described by me from the Lower Cretaceous of Kansas, identified them as species of *Scyliorrhinus*. In company with Mr. Brown, I later examined the outcrop whence he had obtained his specimens, near Lander, Wyo., and found it to be in the upper part of the Atlantosaurus beds, and some 15 or 20 feet below an outcrop containing leaves which Mr. Knowlton identified as Dakota. A search in this horizon disclosed numerous specimens of shark and crocodile teeth, four species of which I identified with species obtained from the mentor beds of the Lower Cretaceous, of Kansas, together with numerous fragments of dinosaur bones, among which I recognized

the genus *Laosaurus* described by Marsh from the Atlantosaurus beds.

It may be objected that the specific identity of fish teeth is too doubtful to correlate such remote horizons, and the objection might be valid for single specimens, or even possibly for single species. In this case, however, I did not find a single form that was not represented in the Kansas beds, and the specimens were abundant. Furthermore, the matrix containing the fossils is so nearly identical with that from Kansas that, had anyone given me specimens, without information of their derivation, I should have unhesitatingly referred them to the Kansas beds. The fact, moreover, is of interest as showing a marine fauna. This horizon in Kansas contains not only these species of fishes, but also crocodiles and dinosaurs which I am unable to differentiate from forms from the Atlantosaurus beds, and the Lander horizon contains fossils described by Marsh from the Atlantosaurus beds. The Kansas horizon is high up in the Lower Cretaceous.

About 50 feet below this outcrop of Lower Cretaceous fossils fragments of Sauropodous dinosaurs occurred in the Lander region. The entire thickness of the Atlantosaurus beds here is not more than 250 feet, to the best of my knowledge.

The upper part of the Atlantosaurus beds is, it seems to me, indisputably Cretaceous; the lowermost part is probably not older than the Wealden, though possibly of Purbeckian age. I therefore strongly protest against the common usage of referring all the fossils from these beds to the Upper Jura. Until more is known of the different faunas contained in it, the only proper designation for the composite faunas included in them is Jura-Cretaceous; this assumes that the Wealden is really Jurassic.

I may add that I cannot agree with Mr. Hatcher in his use of the name "Atlantosaurus beds" for these deposits. The name *Atlantosaurus*, it is generally conceded, has no place in zoölogical literature. His comparison with Fort Union is hardly parallel. Nor can I adopt the name "Sauropoda" for the Opisthocoelia of Owen. No one has ever been in doubt as to what the term Opisthocoelia included, and where every student knew its meaning, a precise definition is superfluous.

Because of certain incorrect statements which have been published recently concerning the discovery of the vertebrate fossils of the Atlantosaurus beds, it will be worth while to give briefly the real history. Probably the first specimen of a vertebrate critically studied by a paleontologist from these beds was that described by Leidy in 1873 in his *Contributions to the Extinct Vertebrate Fauna of the Western Territories*, as *Poicilopleuron valens*, and named *Antrodemus* generically in his plate—a genus apparently identical with that afterwards called *Labrosaurus* by Marsh. This specimen was obtained by Hayden in Middle Park, Colo., where similar specimens were reported to be common. Prior to this time Marsh had observed dinosaur bones at the extreme western end of Lake Como, Wyo., in 1868, but had not appreciated the value of his discovery, nor published anything concerning the fossils. The history of the discoveries later may be given as published by me in the *Transactions of the Kansas Academy of Science* for 1878, as follows. I have substituted only the name of Mr. Beckwith for that of Mr. Berthoud, both of whom had been associated with Mr. Lakes in his investigations.

To an English geologist, Professor Arthur Lakes, of Golden, Colo., credit is due for first detecting the osseous character and appreciating the scientific value of the fossils. While engaged one day in March, 1877, in company with Captain H. E. Beckwith, in collecting Dakota leaves from the summit of the ridge or "hog-back" near Morrison, he discovered a huge caudal vertebra in bas-relief upon a slab of sandstone. Upon further investigation, a large quantity of bones was collected and shipped to Professor Marsh, of Yale College, by whom they were described under the name of *Titanosaurus montanus*. Almost contemporaneously with this discovery the fossils were made known at Cañon City by Mr. O. Lucas, a school-teacher, and by Mr. William Reed, an intelligent section foreman of the Union Pacific Railway. Specimens from the former locality were sent to Professor Cope, of Philadelphia, by whom they were named *Camerasaurus supremus*. Since then numerous other localities have become known in Colorado and Wyoming, and I doubt not that future explorations will bring to light scores of outcrops rich in these vertebrate fossils.

In June or July, 1877, Professor B. F. Mudge, of Kansas, was sent to Morrison by Professor Marsh to exploit, in connection with Professor Lakes, the fossils of that region. From there Mudge went shortly to assist Mr. M. P. Felch in opening the famous Marsh quarry

at Garden Park near Cañon City, afterwards worked by Mr. Hatcher. In early September of 1877 I was sent by Professor Marsh to the Morrison locality, and, a few weeks later, to Cañon City, where I remained until November, when I went to Como, now Aurora, Wyo., to open up the first quarry there, with Mr. Reed, who had discovered bones in this region more than a year before.

A PARTICULAR CASE OF GLACIAL EROSION.[1]

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It is the purpose of this paper to describe a peculiar phase of glacial work, where a layer of stratified rock of considerable area was shoved forward bodily on its bed, and then thrust up out of horizontality. Use is made of this case to explain the manner in which a number of other known dislocations of bed-rock in the vicinity might have been made, as well as to explain how glaciers in general may affect the subjacent rocks under certain circumstances. The present illustration is found near the University of Minnesota, in Minneapolis, about a mile below the Falls of St. Anthony, on the east side of the gorge of the Mississippi. The conspicuous feature of the displacement is represented in the right (southeast) half of the accompanying profile (Fig. 1). The left (northwest) half of the profile is drawn from notes, aided by photographs taken from time to time as ground was excavated in a stone quarry, which has been working obliquely across the line of the profile. The line of the profile corresponds with the direction of glacial movement. There is also, at the time of writing, an exposed section parallel to and corresponding with that of the left half of the figure.[2]

The section which is represented by the profile (Fig. 1) lies near the 800-foot contour line as established by the topographic map.[3] As shown on the map, a terrace lies between the 780 and 800-foot contour. This terrace belonged to the Mississippi River at a stage when the falls were below this point, instead of above it, as they now are. Besides the terrace contour, the occurrence of the river shingle and well-preserved shells of species of *Unio* shown at *R* (Fig. 1), under a layer of peat (*P*), proves that the river once flowed over the

[1] This paper was read before the Minnesota Academy of Sciences, January 3, 1905.

[2] Observations on this exposure have extended over several years. Negatives taken are on file in the Department of Geology, University of Minnesota.

[3] St. Paul quadrangle, U. S. Geological Survey.

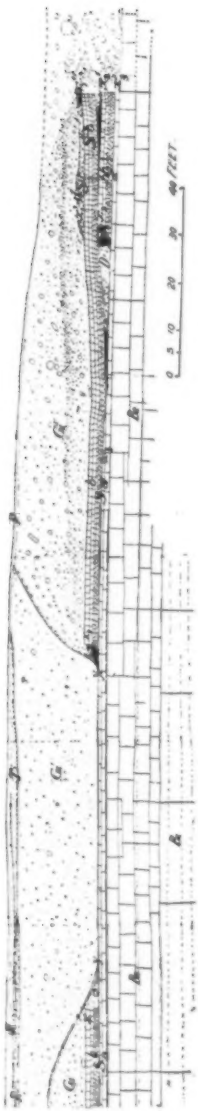

FIG. 1.—Profile showing glacial action from left to right. Strata thrust up on the right or front, and pulled apart on the left. B_1 and B_2, massive limestones; *Sa* to *d*, limestones and shales; G_1, older drift; G_2, newer drift; X to X_3, older glaciated surface, broken; Y to Y_1, newer glaciated surface; R, river shingle; T, terrace sand; P, soil and peat. Vertical and horizontal scales equal.

site. The glacial drift has not, therefore, its original thickness. Twenty feet or more of it have been washed away by the river, and should be restored in interpreting the glacial work in this particular case. In other respects, the accompanying profile explains itself in the main. [Below the soil and peat (P) is terrace sand, T, with the shells of land snails, *Helix, et al.*, in it, and the river shingle, R, with *Unio* shells. Still lower is the glacial till, G_1 and G_2, overlying beds of the Galena (Trenton) series. Of these, the first (lowest) bed, B_1, and the second, B_2, are massive limestones. The lower part of the third bed, *Sa*, is also limestone, but is distinguished by its color, and hard, pyritiferous, crystalline condition. The upper part, *Sb*, consists of several layers of grayish crystalline limestone, separated by uneven clay-shale seams. *Sc* (at the right of Fig. 1) is clay-shale, overlain by limestone, *d*, belonging to the same third bed. *Sa* to *Sd* comprise about half of the third bed of the series, as seen elsewhere in the vicinity. The upper part, here wanting, is shale, with thin and widely separated layers of limestone.

On the right (southeast) of the section there are three remarkably glaciated surfaces, X_1 (top of *Sb*), X_2 (top of *bb*), and X_3 (base of *bb*), one above the other. It is this phenomenon, noticed more than ten years ago, which led me to study this locality. At that time the part of the profile which is represented

in broken lines was exposed by quarrying, while the rest was concealed. This part, represented in broken lines, is drawn from memory.

The part of the section shown in the right half of the profile was exposed several years later, and showed that the glacial movement was from the westward, not from the eastward or southeastward, as was originally supposed. Only during the past year has the left half, as represented in the profile, been cut across in such ways as to reveal the two drift deposits, G_1 and G_2, as well as the undisturbed part of the stratum *Sb*.

It is now evident that the newer till, marked G_2, represents the position of the ice which forced the stratum *Sb* apart, and shoved the one part, *Sb*, with its overlying drift, G_1, from X to X_1. At the same time, the surface between Y and Y_1 was scratched, though not much worn. The glacial deposit G_1 is older than G_2, though the two are in contact. They are essentially alike, though the proportion of pebbles is greater in one than in the other, and the boundary between them is structurally well marked.

The mass of shale and limestone which was moved forward rests on the surface of a stratum which, from Y_1 to X_3, is not glaciated or cut, being protected by a clay lamina, while from X_3 to X'_3 the surface below the shoved block is glaciated, and one thin layer, for the greater part of the distance, has been ground away. In the undisturbed strata at the left (northwest) there is a clay-shale lamina at the base of *Sb*, and it is the lowest of several such partings between the limestone layers. The disturbed mass started to move upon the lowest shaly lamina, and was driven out over a denuded or already glaciated surface X_3 to X'_3.

All the glaciated surfaces, excepting that which is indicated by Y to Y_1, were originally one, running from X on the left, along X_1, to X''_1, which was originally continuous with X_2 and down along X'_3, as we see if we imagine the disturbed strata put back in place. Then with the second till, G_2, eliminated, we obtain the conditions which preceded the movement. In this it will be noted, further, that the interval or gap, from X to X_1, on the left, which should represent the distance traveled, is less than the distance from X_2 to X'_2 plus that from X_3 to X'_3, which should also represent the distance traveled.

Before this relation is explained it should be noted that the drift-wedge, marked *D*, represents a clay-shale and till intermixture entrapped under the upturned strata.

To explain how the block *bb* came to lie under the main block (*Sb*) in the section, the following details are given. The major joints in the rock strata run generally in north-to-south and east-to-west directions. The glacial movement was oblique to those directions, in this case, from the northwest, and the blocks were therefore driven in a diagonal direction. A side thrust may have been given as the one sheared upon the other. The under part or block, *bb*, also probably rotated in front of the drift, *D*, as it shoved forward. As the result of the rotation, the distance traveled by the mass seems greater than it probably was. On the other hand, the distance of the gap, *Y* to Y_1, owing to the direction of glacial movement not being exactly diagonal to the blocks, may be a little shorter than the whole distance traveled.

The most conspicuous feature in the exposed section—viz., the disjoined under block, *bb*—is not the matter of first importance. Its position is incidental, as is shown by comparison with another part of the same mass, which still lies on the other side of the boulevard. In this there is normal drift merely, in place of the block, *bb*, and the larger body of limestone has moved upward quite the same.

One feature of special significance is the upturned front of the transported mass of limestone and till. Altogether, the front appears to have the shape of the point of a spoon. Another significant feature is the abrupt disjoining of strata at the rear. The strata were pulled apart. These features appear in other occurrences. In other exposures, beds of clay-shale and included limestones, now in place, are seen to end abruptly against the glacial till, as the stratum *Sb* does on the left of this section. One such exposure which is to be seen at the time of this writing is in another quarry, half a mile to the southeast of the locality of the section shown in Fig. 1, on the west bluff of the river. Here the clay-shale beds, some 10 feet thick, are cut off nearly vertically by the till, the latter lying on the leeward side in relation to glacial movement. Several other similar occurrences have been seen in the vicinity. They differed, however, in having the abrupt end of the clay-shales more or less sloping.

The two chief features in this case were, I think, formed under the following circumstances: At an early stage, glacial erosion cut the stratified bed-rock unevenly, so that, when deposited, the till, G_1 rested at the left on the clay-shales, *Sc* (now shoved over to the right), in the middle on the limestone with shaly seams *Sb*, and toward the right on the limestones *Sa* and B_2. The later ice-movement was over the till G_1. Its friction with the till produced stress, which was transmitted to the stratified rocks, and they yielded along the lowest clay-shale seam, moving forward. The initial disjoining of the stratum (*Sb*) and the till $(G)_1$, may be ascribed to unequal stress from unequal friction of the glacier on its bed. After the gap began

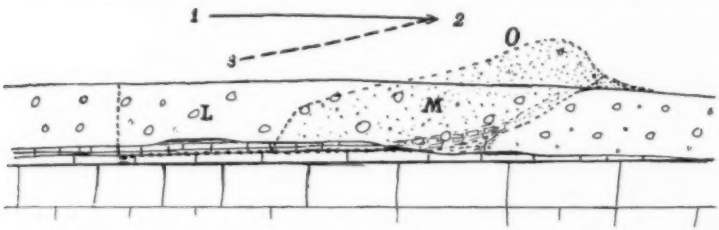

FIG. 2.—Diagram showing change of direction of ice-movement from 1–2 to 3–2 as the mass *M* moves from *L* toward *O*. Original position of ice and subjacent rocks in solid line; change by movement, in broken lines.

to open, the ice settled into it, while the rock-mass was moving forward. The upward thrust in front and the gap at the rear may be correlated through a compensating movement in the glacial ice, as illustrated in Fig. 2. In this diagram the original position of the ice, the older drift, and the subjacent stratified rocks are represented in solid lines, while the result of the movement is indicated by broken lines and dots. Ice filled into the gap, *L*, as the drifted mass *M* tended to fill the position at *O*, in its stead. The horizontal line (1–2) indicates the original direction, while the other (3–2) indicates the subsequent direction, and the angle (1–2–3) the relative rotation of the ice-mass in compensating.

Whether this work of the glacier was done far from or near to the front of the ice-sheet does not appear. The reason why the drifted mass stopped where it is now seen is also not evident, and may be a very incidental matter. Notably, however, the manne

in which a start could have been made by those masses which were carried much farther, is shown.

It may also be argued that a series of masses could, under repeated cause, lodge one behind the other. An explanation for the entrapped drift-wedge, *D*, in the section (Fig. 1) may be that the block *bb* was set forward, and a gap behind it filled with till before the main mass started. As to general application of this particular case, any mass of till, resting on a lamina of clay, might be started and then rotated forward in like manner; but with no stratified rocks as a distinctive mark, such cases might be difficult to interpret.

Evidence tending to prove that the glaciers have elsewhere plowed up the bed-rock of the region is not rare. It has been seen in the excavations for buildings, stone quarries, and road-gradings in Minneapolis and St. Paul, where the underlying rock is of Ordovician age, and is exposed along the gorge of the Mississippi. Elsewhere it is generally concealed by the glacial drift. In these exposures, blocks of limestone are often seen scattered or grouped in the bowlder-clay, as if the rock had been torn up in large masses, and are so exactly like the rock which exists *in situ* in this region as to be unmistakable. While they might have come from miles away, so far as the kind of rock is concerned, they are more probably torn from the sides of preglacial valleys now buried under the glacial deposits in this vicinity. Of more particular importance here are certain clay-shale masses which occur in the bowlder-clay. By the character of the clay and of the included lenticular masses of crystalline limestone, and by the contained fossils, the original position of these clay-shale masses may be determined. One or more of the beds whence they came are still in place over a great part of this area, under the drift and above the limestone. The shale-masses in the drift have presumably been torn up not many miles from the place where they now lie.

These drifted clay-shale masses are generally not weathered, and retain their original blue color. They are often unmixed with pebbles of northern drift, and in a few cases they retain their original stratification, as well as their fossils. Small masses are most common and least distinct. The largest are 100 feet or more in horizontal diameter, and 50 feet or less thick. They generally have upturned

fronts, which are also relatively more disrupted than are the rears. As an example I may mention an occurrence in St. Paul, already briefly described.[1] At that place a mass of shales, representing recognized beds of the Galena (Trenton) series, covers about an acre of surface. As shown in the grading of the streets which cross it, the shale is surrounded by northern drift, which lies over part of it, and probably under all of it. Other cases of similar import were cited in the article referred to.

The manner in which the glacier transported these large masses, without overturning them, was a matter of wonder until the discovery of the case here described. This particular occurrence shows at least how the great clay-shale masses may have been plowed up.

[1] *Journal of Geology*, Vol. VI, p. 688.

NOTE ON THE GLACIER OF MOUNT LYELL, CALIFORNIA[1]

WILLIS T. LEE
Washington, D. C.

The writer had the privilege of visiting the glacier on Mount Lyell on August 17 and 18 of the present year (1904), and of securing the photographs accompanying this note. Mount Lyell is one of the well-known peaks of the High Sierra, although it is by no means the highest, the elevation being only 13,090 feet. On the northern face of the mountain lies a body of ice something over a mile in east-and-west length, and extending down the slope about half a mile. It consists, in reality, of two glaciers lying side by side, and separated in part by a narrow tongue of rock. The present aspect of the glacier is shown in the accompanying photographs.

Two phenomena seem especially worthy of note. First, there is an absence of any large amount of morainal material except at the immediate terminus of the ice. Lyell Canyon, which was formerly occupied by the extended Lyell Glacier, was examined for a distance of about fourteen miles, and only scattered bowlders and small beds of morainal material were noted until the present terminal moraine was reached. Abundant evidence of glacial action, however, is present throughout the valley in the form of polished and grooved surfaces, *roches moutonnées*, and domes. The retreat of the glacier to its present position must have been rapid. It is doubtful if the volume of glacial débris now found in Lyell Canyon is much greater than the volume that would be contained at any one time in a glacier filling this canyon to the extent which Lyell Glacier did in former times.

The second phenomenon to which I call attention is apparent on examination of the photographs. In contradistinction to its former rapid retreat, the front of Lyell Glacier has remained at or near its present position for a considerable length of time. It will be noted

[1] Published by permission of the director of the U. S. Geological Survey.

that the ice crowds closely upon the terminal moraines. There is no space between the face of the glacier and the moraine to indicate recent recession. It will also be noted that a very small portion of the old ice is exposed, the greater part of the surface being covered with last winter's snow. At that altitude no great amount of snow will melt after August 18—the date of my visit—before a fresh snow-

FIG. 1.—Lyell Glacier, western lobe. (The snow in the foreground is not a part of the glacier, and the first two masses of rock are not moraines. The moraine is nearly covered with snow.)

fall begins the winter's accumulation. It will be noted, especially in Fig. 1, that fresh snow in large quantities lies outside of the moraines as well as covering the greater part of the glacier. The terminal moraine of the western lobe of the glacier is largely concealed from view by fresh accumulations of snow. The foreground is occupied by a lake nearly covered with ice which has remained all summer, and which is buried on the glacier-ward side beneath many feet of snow. The large mass of snow in the foreground, since it has nothing to do with the main glacier, although it has glacial motion of its own,

can be neglected. Considering, then, only the masses of snow immediately outside of the moraines, the quantity indicates that it must be due to several years' accumulation. In some cases the extra-morainal masses are several hundred feet wide and, judging from the topography, must be forty feet or more in depth.

Turning to an examination of Fig. 2, there is less recent snow than appears in the western lobe, and a larger portion of the old ice is exposed, perhaps because this lobe descends considerably lower than the western lobe. The nose of the glacier is here pushed hard upon the moraine, so that the front of the ice and the moraine form a single slope. The loose morainal material is accumulated in a steep slope, with its base forming a comparatively sharp outline with the rock on which it rests. The relations are such as strongly to suggest that this lobe of the glacier is overriding its terminal moraine and dropping the fresh material at the front.

During the summer of 1883, I. C. Russell photographed this glacier, and his photographs were published in the *Eighth Annual Report* of the U. S. Geological Survey. Twenty years later, during the summer of 1903, G. K. Gilbert secured photographs of the same glacier and published them in the *Bulletin of the Sierra Club*, in an article entitled, "Variations of Sierra Glaciers." In comparing his photographs with those of Professor Russell, Mr. Gilbert says:

> The glacier seems now to have almost precisely the same size as at an earlier date, the only suggested change being a slight shrinkage near the west end. The arrangement of the numerous moraine ridges is precisely the same as in 1883, from which it may be inferred that the glacier has not in any later year been materially larger than then. It might, however, have diminished and afterward increased.

Later he observes: "Lyell Glacier was quite as free from snow in the summer of 1883 as in 1903."

From a comparison of Russell's photographs, taken in 1883, Gilbert's, taken in 1903, and the writer's, taken in 1904, it is evident that little change has taken place since 1883. All the main features are the same. Careful comparison, however, indicates that small arms of ice reaching up the rock faces are slightly larger than they were twenty-one years ago, and certain small areas of rock, which

then appeared above the surface, are now covered. A comparison of Mr. Gilbert's photographs of the western lobe with the writer's, taken only one year later, indicates an increase which can be detected from the photographs. For example, in Fig. 1 it will be noted that the snow near the top of the peak above the Bergschrund is continuous to the top. In Gilbert's photograph, taken only one year

FIG. 2.—Lyell Glacier—eastern lobe.

earlier, a continuous line of rock appears across the arm above the Bergschrund. It is very evident, from the clothing of new snow remaining on the glacier through the summer, that the snowfall of last winter has increased the volume of the glacier. It is evident, from the relation of the ice to the moraines, and from the records above quoted, that little or no recession has occurred in recent years. The relation of the morainal front to the underlying rock at the eastern lobe, and the large accumulations of extra-morainal snow in the western lobe, suggest that the glacier may be slowly advancing. It may be confidently stated that for the past twenty-one years there

has been, on the whole, no decrease in volume. It may be further confidently stated that since the formation of the present terminal moraines there has been a somewhat marked increase in the volume of ice, as indicated by the large masses which have accumulated in front of the moraines.

EXAMPLES OF JOINT-CONTROLLED DRAINAGE FROM WISCONSIN AND NEW YORK

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I. THE RICHLAND CENTER QUADRANGLE OF WISCONSIN

A neighboring district to the one under consideration and bordering on the upper Mississippi has been cited by Daubrée[1] as one where the influence of joints upon drainage lines has been manifested in a striking manner.

> Scattered and cuboidal blocks (bluffs and knolls) resemble ruins, deep crevasses, networks of nearly vertical valleys, of which the picturesque form strikes all of the travelers to the upper Mississippi.[1]

Farther up the Wisconsin, Van Hise has ascribed the location of the well-known Dells, or side valleys, to the position of joint planes within the underlying rocks.[2] Subsequently Buckley[3] has made an extended study of joint planes developed in the quarry rocks of the state as respects their bearings, which he has summarized as follows:

> The joints in the sedimentary rocks strike in four main directions. The prevailing general direction of the joints is northeast and southwest. The other directions are northwest and southeast, east and west, and north and south.

Inspection of Buckley's map discloses the fact that the diagonal bearings do not represent single, but several joint series.

Under the writer's direction, Mr. E. C. Harder, a member of the senior class of the University of Wisconsin, has undertaken an investigation of the joint series which are developed within the Paleozoic rock formations of southwestern Wisconsin, and has noted correspondences in orientation between the drainage lines and the joint planes. The investigation has covered districts distributed over an

[1] *Géologie expérimentale* (Paris, 1879), Vol. I, pp. 337, 355–57.

[2] C. R. Van Hise, "The Origin of the Dells of the Wisconsin," *Transactions of the Wisconsin Academy of Sciences, Arts, and Letters*, Vol. X (1895), pp. 556–60.

[3] E. R. Buckley, *Bulletin IV*, Wisconsin Geological and Natural History Survey, 1898, pp. 456–60.

area comprising about 7,000 square miles in the southwestern part of the state, and has also included areas surrounding the cities of Madison and Milwaukee. In all cases the joints are in vertical series, particularly well developed in the more compact limestones. Mr. Harder's report upon the area will soon be published, and it is possible here to refer to but a single area among those examined.

For a considerable portion of the Richland Center Quadrangle[1] Mr. Harder's summary of the joint directions which he observed is as follows:

JOINT SERIES OCCURRING NEAR RICHLAND CENTER, WISCONSIN

N. 5° W.–1	N. and S.–7	**N. 5° E.–19**
N. 10° W.–2		N. 15° E.–5
N. 12° W.–2		N. 20° E.–5
N. 15° W.–14		N. 22° E.–2
N. 20° W.–3		**N. 25° E.–12**
N. 25° W.–16		N. 30° E.–2
N. 28° W.–3		**N. 35° E.–35**
N. 30° W.–5		N. 40° E.–1
N. 35° W.–23		**N. 45° E.–20**
N. 40° W.–1		N. 46° E.–2
N. 45° W.–14		N. 50° E.–6
N. 50° W.–5		N. 52° E.–1
N. 55° W.–23		**N. 55° E.–9**
N. 60° W.–9		N. 60° E.–5
N. 65° W.–9		**N. 65° E.–12**
N. 70° W.–5		N. 70° E.–5
N. 72° W.–2		N. 72° E.–3
N. 75° W.–11		**N. 75° E.–24**
N. 80° W.–4		N. 80° E.–2
N. 82° W.–2		**N. 85° E.–9**
N. 85° W.–5	E. and W.–11	

It appears that in order of approximate numerical superiority the more important joint directions of the Richland Center district are: N. 35° E., N. 75° E., N. 55° W. (or N. 55°–65° W.), N. 85°–90° E., N. 35° W., N. 45° E., N. 5° E. (or N.–N. 5° E.), N. 25° W., N. 15° W., and N. 45° W. The tendency of the five-degree interval to appear is noticeable, and indicates that here, as elsewhere, the observations of slightly curving planes become adjusted to the larger unit of the

[1] Surveyed, but not yet published.

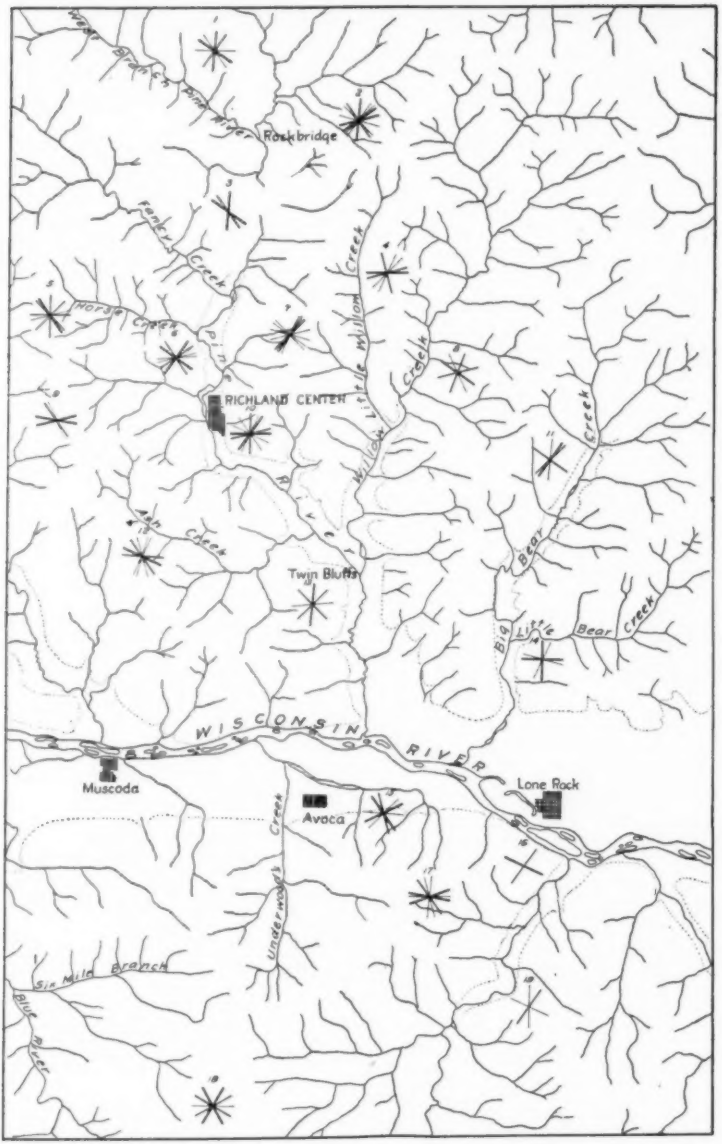

FIG. 1.—Joint and drainage map of a portion of the Richland Center Quadrangle in southwestern Wisconsin. (Prepared by Mr. E. C. Harder.) Scale, 5 miles to the inch. The dotted lines represent bluffs, while the stars indicate the local importance of joint series.

compass dial. The order of importance of the series for the local district is not quite the same as that for the larger district of which it is a part, for beyond all question the east-west direction is the predominant one. Of the entire region, also, so far as it contains ores, the mineralized crevices are mainly equatorial and meridional, less frequently "quartering" (corresponding to a diagonal series).

A glance at the map of Fig. 1 is sufficient to show that there

FIG. 2.—Control of direction of a stream by prevailing joint planes in southwestern Wisconsin. (Photograph by Mr. E. C. Harder.)

is more than an accidental coincidence of joints and drainage systems. The map further reveals the distribution of the observations, from which distribution their relationship to near-lying drainage lines may be made out. That the correspondences were not due to mere coincidence is further attested by actual disclosures in the stream valleys where the zigzags of the course follow actual joint planes (see Fig. 2).

The Richland Center district is included within the driftless area of Wisconsin. Evidence of joint-controlled drainage is also furnished by a district lying within the glaciated area of western New York.

II. THE FINGER LAKES DISTRICT OF WESTERN NEW YORK

The Finger Lakes district has long been a classical one for the perfection of its joint planes, a cut from the locality having been used by Dana in his *Manual of Geology* as the type illustration of

FIG. 3.—Canyon formed along a joint plane. Enfield Gorge near Ithaca, N. Y. (Photograph furnished by Professor R. S. Tarr.)

joint structures. Later photographs, which the writer owes to the courtesy of Professor Tarr, of Cornell University, show beyond question that the joint system has exercised an important control

over the water courses. Striking examples of this kind are furnished by Figs. 3-5 and 4, while Fig. 5 brings out with special clearness the dominant rectangular system which is developed on the shore of Cayuga Lake.

This region about the lakes in western New York has been made the subject of many papers, owing to its topographic peculiarities and the curious distribution of the lakes themselves. Among the

FIG. 4.—Control of direction of water course by joint planes within the basin of Cayuga Lake. (Photograph furnished by Professor R. S. Tarr.)

more important of these are papers by Lincoln,[1] Brigham,[2] Tarr,[3] and Dryer.[4]

In these papers the peculiar topography of the lake basins is, on the one hand, ascribed to sub-aërial water erosion, and, on the other

[1] D. F. Lincoln, "Glaciation in the Finger Lakes Region of New York," *American Journal of Science* (3), Vol. XLIV (1892), pp. 290–301.

[2] Albert P. Brigham, "The Finger Lakes of New York," *Bulletin of the American Geographical Society*, Vol. XXV (1893), pp. 203–23.

[3] Ralph S. Tarr, "Lake Cayuga, a Rock Basin," *Bulletin of the Geological Society of America*, Vol. V (1894), pp. 339–56, Plate XIV.

[4] Charles R. Dryer, "Finger Lakes Region of Western New York," *ibid.*, Vol. XV, pp. 449–60, Plates 37–41.

hand, to glacial erosion. At the St. Louis meeting of the Geological Society of America, held in December, 1903, the writer pointed out that, irrespective of which of the two agents had performed the major part of the work of excavating the valleys, the cause of the striking rectilinear extension of the valleys and their peculiar arrangement necessarily called for a control of whichever of the agents accomplished the work. From Professor Tarr, who was present at the

FIG. 5.—Vertical rectangular joint set on east shore of Cayuga Lake, Ithaca, N. Y. (Photograph furnished by Professor R. S. Tarr.)

meeting, it was learned that Mr. Charles G. Brown, editor of the *Holstein-Frisien World*, had undertaken the measurement of joint directions within the Cayuga Lake Basin as a thesis for graduation when a student at Cornell University. Mr. Brown has very kindly placed his results at the writer's disposal, and from a somewhat extensive survey of literature the writer is convinced that they constitute not only the most extensive, but also the most consistent, series of observations of the kind that has yet been made. This is probably in part to be explained by the perfection of the joint system within the district studied.

Mr. Brown has measured the direction of a total of 1,004 joints, most of which are in the vicinity of Ithaca, N. Y. Some of the localities examined are Six Mile, Cascadilla, Fall, and Buttermilk Creeks; the Bates, Sheehey, Driscoll, and Veder quarries; Coy's, Shugar's, and Estey Glens; and other localities in and about Lansing, Taughannock, Portage, Genesee, and Hamilton. Another set of observations is taken from the Cayuga Creek gorge, Havana and

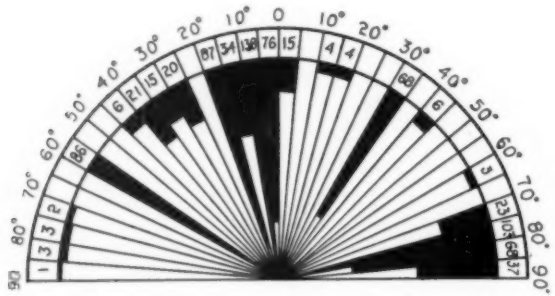

FIG. 6.—Diagram to show the orientation of joints in the Cayuga Lake basin of western New York (Brown).

Watkins Glens, the west shore of Seneca Lake, and localities about Norwich. The results of this investigation are not published, but through the courtesy of Mr. Brown I am permitted to make use of his results in this article. After a careful enumeration of the joint directions observed, Mr. Brown says in his thesis:

> The correlation presented in Fig. 4 seems to indicate that these joints constitute two orthogonal systems. Those whose direction trend N. and N. 45 degrees W., and N. 70 degrees E. and E., constituting the major system; while those whose direction trend between N. and N. 20 degrees E., and N. 70 degrees W. and W., constitute the minor system. It will also be seen that the major system contains 551 of the 572 joints correlated,[1] or 96 per cent. of the whole number; while 374, or 67 per cent., of those constituting the major system lie between N. and N. 45 degrees W.

Mr. Brown's results covering this area I have brought together below in a single table, in order to show their orientation as respects the entire area:

[1] This does not include the later work.

N. 2° W. 1		N.–S. 15	N. 4° E. 1	
N. 4° W. 30				
N. 5° W. 6	**43**		N. 5° E. 1	
N. 6° W. 7			**N. 10° E. 2**	
N. 8° W. 2			N. 12° E. 2	
N. 10° W.	**139**		N. 16° E. 4	
N. 12° W. 14			N. 20° E. 2	
N. 15° W. 54	**88**		**N. 30° E.**	**68**
N. 16° W. 34				
N. 18° W. 4			N. 45° E. 6	
N. 20° W.	**288**		N. 60° E.	**3**
N. 24° W. 5				
N. 26° W. 1				
N. 30° W. 20	**35**			
N. 34° W. 15				
N. 40° W.	**51**		**N. 70° E. 21**	
			N. 72° E. 8	**131**
N. 44° W. 6			**N. 74° E. 90**	
N. 60° W.	**86**		**N. 75° E. 12**	
N. 74° W. 1			N. 78° E. 1	
N. 76° W. 1			**N. 80° E.**	**62**
N. 80° W. 3			**N. 85° E.**	**35**
N. 84° W. 1		E.–W. 1	N. 88° E. 2	

Making use of five-degree intervals the above results are graphically summarized in Fig. 6.

In order of relative numerical importance the joint directions of the district are thus found to be: N. 20° W. (288), N. 10° W. (139), N. 70°–75° E. (131), N. 15°–16° W. (88), N. 60° W. (86), N. 30° E. (68), N. 80° E. (62), N. 40° W. (51), N. 4°–6° W. (43), N. 30°–34° W. (35), N. 85° E. (35), and N.–S. (15). These twelve directions include 941 of the 1,004 measurements, and, with the exception of the directions N. 12° W., whose fourteen observations should perhaps be added to the 139 directed N. 10° W., no other direction is represented by more than six measurements.

From the above figure it will also appear that there is an orthogonal joint set having directions N. 30° E., and N. 60° W. There are also two other near-lying orthogonal sets, the one having direction N. 74°–75° E. and N. 10°–16° W., and the other N. 80°–85° E. and N. 4°–6° W. In the vicinity of Watkins Glen, the first-mentioned set is the dominant one, while at the other localities this set is rarely observed, the other sets taking its place.

These data collected by Mr. Brown make it possible to see whether any correspondences exist between the dominant hydrographic lines of the district and the underlying fracture system. A map of the

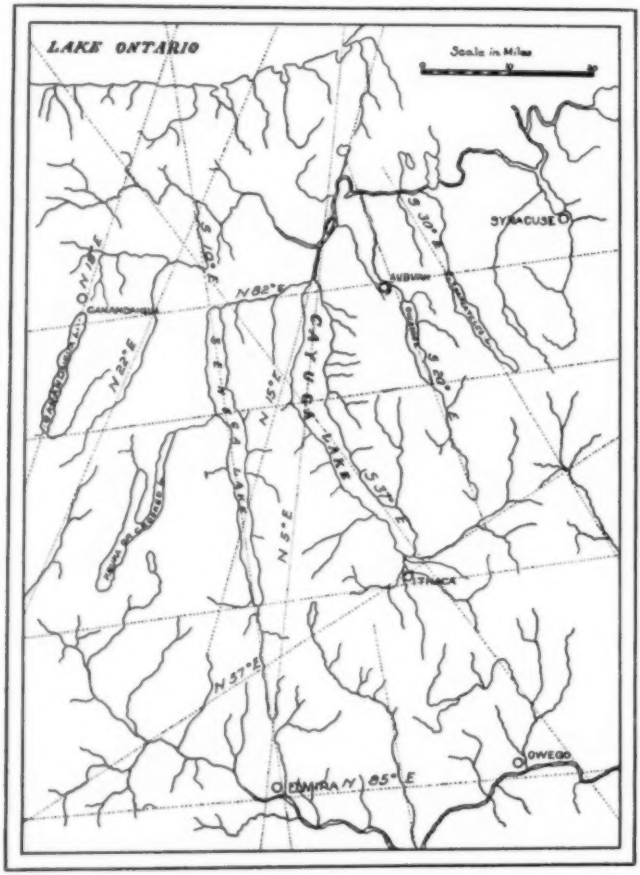

FIG. 7.—Map of the Finger Lake region of western New York, with indication of the more striking hydrographic lines.

district based on the one prepared by the College of Engineering of Cornell University is reproduced in Fig. 7.

The most striking hydrographic line of the district may be called

the Seneca line, which is directed about N. 10° W., and which for a distance of nearly 60 miles is outlined in part by Seneca Lake itself, to the south by an open valley which extends as far as Elmira, and to the north by a reach of Canandaigua Outlet. Three lineaments, nearly parallel, are directed in a nearly perpendicular direction to the Seneca line, and may be designated respectively as the Seneca Falls line, the Penn Yan line, and the Watkins Glen line. For a portion of their extent these lines correspond to the boundaries of formations, and the fact that they are fall lines is thus in part explained. Their alignment, however, is no less significant, since the joint planes have so largely determined the areal limitation of the formations. The line of Owasco Lake is directed N. 20° W., and may be followed in the drainage for a distance of about 40 miles. The line of Skaneateles Lake and Tioughnioga River together make a prominent lineament directed N. 30° W., and followed for a distance of about 40 miles. Upper Cayuga Lake and its extension in drainage lines to the northwestward and southeastward mark out a lineament whose direction is N. 37° W., and which may be followed for some 70 miles. Less striking lineaments are directed along Canandaigua Lake (N. 18° E.), Cayuga Outlet (N. 15° E.), and along Flint and Twelve Mile Creeks (N. 22° E.).

Comparing, now, these lineaments with the joints observed by Mr. Brown, we have:

Lineament and its Bearings	Approximate Length Indicated	Number and Bearing of Joints Observed by Mr. Brown
Seneca line (N. 10° W.)	60 miles	139 (N. 10° W.)
Owasco line (N. 20° W.)	40 miles	288 (N. 20° W.)
Upper Cayuga line (N. 37° W.)	70 miles	66 { 51 (N. 40° W.) / 15 (N. 34° W.)
Skaneateles line (N. 30° W.)	40 miles	35 (N. 30° W.)
Seneca Falls line (N. 82° E.)	40 miles	97 { 62 (N. 80° E.) / 35 (N. 85° E.)
Penn Yan line (N. 82° E.)	40 miles	
Watkins Glen line (N. 82° E.)	20 miles	
Cayuga Outlet line (N. 15° E.)	20 miles }	4 (N. 16° E.)
Canandaigua line (N. 18° E.)	15 miles }	

The directions of the Seneca, Owasco, Upper Cayuga, and Seneca Falls lines are respectively those of the second and first in relative numerical importance among the joints observed in the district, as

will be seen by comparing with the table on p. 371. The Skaneateles line is also along one of the most prominent directions of jointing. Of the less strongly indicated directions (Canandaigua line and Flint and Twelve Mile Creeks line, N. 18°–22° E.) no strong indication of control by jointing is observable, though the direction N. 16° E. is that of four observed joints, whereas no other directions between N.–S. and N. 30° E. have more than two representatives among those recorded.

Reviews

Vermont Geological Survey: Mineral Industries and Geology of Certain Areas. By GEORGE H. PERKINS, PH.D., State Geologist and Professor of Geology, University of Vermont. (Fourth Biennial Report.) Pp. 1–227; Plates I–LXXXI.

This report contains a description of the investigations conducted by the Survey during 1903–4. The report proper is prefaced by a sketch of the life and work of Charles Baker Adams, the first state geologist of Vermont, and a list of the publications on the geology of Vermont.

The chapter on the mineral resources of the state, by the state geologist, concerns itself chiefly with the various building and ornamental stones of the state. A map shows the approximate location and extent of the various granite, marble, and slate areas. The nonmetallic minerals, soapstone, talc, kaolin, fireclay, and asbestos, and the metallic minerals, gold, silver, copper, and platinum, are briefly treated.

C. H. Hitchcock discusses the glaciation of the Green Mountain Range. It is evident from a review of the facts that all the New England and northern New York elevations were swept over by the Hudson River lobe of the Labrador glacier as it advanced down the St. Lawrence, Lake Champlain, and Hudson River depressions, filling these great valleys, and spreading eastward and westward over the elevated mountain districts on either side.

W. F. Masters, in a preliminary report on a portion of the serpentine belt, shows that the serpentines are largely confined to a broad belt of talcose, micaceous schist. Three distinct types of rock occur—talcose micaceous schist, amphibolites, and serpentine, the latter resulting from the gradual alteration of the amphibolite. Serpentine occurs in two localities, Lowell and Belvidere. In both places the rocks have been sheared and crushed. The maximum amount of crushing and fracturing occurred near the upper and lower limits of the zones, and along fault planes. It is along these fracture lines that the asbestos has developed in paying quantities.

The chapter on the geology of Grand Island County, by the state geologist, describes the various formations and their economic importance. The county comprises Alburg peninsula, three large islands, North Hero, Isle La Motte, Grand Isle, and a group of smaller islands which nearly fill

the northern end of Lake Champlain. The surface rock of Alburg and North Hero is Utica shale, while on Isle La Motte and Grand Isle patches of the Beekmantown, Chazy, Black River, Trenton, and Utica formations occur. The entire region is underlain by Ordovician rocks. A large part of Isle La Motte is covered by glacier clay and beaches. The southern end of Grand Isle has numerous dikes. The chapter closes with a description of the Stromatoceria, and similar forms of the Chazy, of Isle La Motte.

The report on the lignite or brown coal of Brandon and its fossils, embraces a brief résumé of the literature relating to the discovery age, origin, geological occurrence, and fossils of the lignite deposits. To this is added a note on the geological relations of the Brandon lignite, with map, by T. N. Dale, of the United States Geological Survey, and a note on the Brandon clays, by J. B. Woodworth, of the New York State Survey. The age of the Brandon formations is not determined. The discussion closes with a description of the fossil forms of the Brandon lignite, and plates illustrating most of the species studied.

The chapter on hydrology, also by Dr. Perkins, states that springs are the chief source of Vermont water-supply. Wells 10 to 30 feet in depth are used in a few localities. Deeper wells are seldom used, and are limited to the western part of the state. In Champlain Valley several flowing wells have been drilled. The joint investigation of the underground water-supply in Vermont by the state and United States Geological Surveys is still in progress.

A. R. S.

The Manufacture of Hydraulic Cements. By ALBERT VICTOR BLEININGER, B.Sc., Instructor in Ceramics, Ohio State University. Geological Survey of Ohio, Fourth Series, Bulletin No. 3 (1904). Pp. xiv+391.

This volume embodies the results of four years' work, and is a valuable contribution to the subject of cement manufacture. Some idea of the scope of the bulletin may be gained from the headings of the chapters, which are as follows: "General Considerations on the Hydraulic Cements;" "Raw Materials of the Cement Industry;" "Analysis and Testing of the Raw Materials;" "Manufacture of Puzzuolane and Natural Cements;" "On the Nature of Portland Cement;" "The Compounding of Portland Cement Mixtures;" "Winning and Preparation of the Raw Materials;" "The Burning of Portland Cement—the Grinding of the Clinker and General Arrangements of Plants;" "The Properties of Portland Cement and the Testing of Cement." Several of these chapters are of more than

ordinary interest, and the volume will be useful to all who are interested in the manufacture of cement.

The various methods of making chemical analyses of the raw materials are given in detail. Following the chemical analyses is a series of mechanical analyses. These mechanical analyses are given because the physical character of the clay has an influence on its chemical activity when the cement is burned.

The chapter on "The Nature of Portland Cement" contains the results of investigations since 1887. The preparation of this summary must have required considerable labor, for many of the original papers are printed in French or German. The results of the author's investigations form a valuable contribution to the subject.

Every detail of cement manufacture is explained from the mining of the raw materials to the pulverizing and testing of the finished product. One of the most important features of the volume is the series of contributions made by the author to various problems of cement manufacture.

On pp. 155–57 the author gives a list of the unsolved problems connected with the chemical and physical analysis of cements. A perusal of this list indicates that there is a large field open to the investigator who has a thorough knowledge of chemistry and physics.

A few pages are devoted to a description of Ohio cement plants, with a statement of the raw materials used and the size and capacity of each plant.

G. C. M.

Preliminary Report on the Ohio Co-operative Topographic Survey, November 15, 1903. By C. E. SHERMAN. Pp. 227.

This work has been in progress three years, the average appropriation by the state being $25,000 per year. To this appropriation the United States Geological Survey adds an equal amount, besides bearing all the expense of engraving and printing the maps. It is estimated that the entire state will be mapped within five years at a cost, to the state, of $25,000 per year.

The maps are made in accordance with the general plan of the United States Geological Survey, the only exceptional feature being the numbering of the sections. It is proposed to indicate the areas of woodland after the maps are printed. Numbering the sections and indicating the wooded areas will add much to the value of the maps.

G. C. M.

Recent Publications.

—Bain, H. Foster, Zinc and Lead Deposits of Northwestern Illinois. [Bulletin No. 246, U. S. Geological Survey.]

—Bauer, L. A., Terrestrial Magnetism; Results of Magnetic Observations Made by the Coast and Geodetic Survey Between July 1, 1903, and June 30, 1904. [Appendix No. 3, Report for 1904.]

—Bleininger, A. V. Manufacture of Hydraulic Cements. [Bulletin No. 3, Geological Survey of Ohio, 4th series.]

—Clough, C. T., and Harker, Alfred. The Geology of West-Central Skye, with Soay. Explanation of Sheet 70. [Memoirs of the Geological Survey of Scotland, 1904.]

——Corstorphine, Geo. S. The History of Stratigraphical Investigation in South Africa. [Reprinted from the Report of the South African Association for the Advancement of Science, Johannesburg Meeting, 1904.]

——— The Geological Relation of the Old Granite to the Witwatersrand Series (Read March 9, 1904). [Reprinted from the Transactions of the Geological Society of South Africa, Vol. VII, Part I, 1904.]

—Davenport Academy of Sciences, Proceedings of the, Vol. IX, 1901–1903. [Davenport, Iowa, 1904.]

—Hatch, Frederick H., and Corstorphine, Geo. S. The Petrography of the Witwatersrand Conglomerates, with Special Reference to the Origin of the Gold (read November 14, 1904). [Reprinted from the Transactions of the Geological Society of South Africa, Vol. VII, Part III, 1904.]

——— The Geology of the Bezuidenhout Valley and the District East of Johannesburg (read August 8, 1904). [Reprinted from *ibid.*, Part II, 1904.]

—Hatch, Frederick H. The Oldest Sedimentary Rocks of the Transvaal (read December 12, 1904). [Reprinted from *ibid.*, Part III, 1904.]

—Hobbs, Wm. Herbert. The Frontier of Physiography. [Reprinted from Science, N. S., Vol. XVIII (1903), No. 460, pp. 538–40.]

——— Lineaments of the Atlantic Border Region. [Bulletin of the Geological Society of America, Vol. XV (1904), pp. 483–506, Plates 45–47.]

——— The Tectonic Geography of Eastern Asia (reviews and translations). [From the American Geologist, Vol. XXXIV (1904), pp. 69–80, 141–51, 214–26, 283–91, 371–78.]

—Maitland, A. Gibb. Preliminary Report on the Geological Features and Mineral Resources of the Pilbara Goldfield. [Bulletin No. 15, Geological Survey of Western Australia; Perth, 1904.]

—Maryland Geological Survey, Highway Division. The New State and Road Law; How Improved Roads May be Secured under its Provisions. [1904.]

—Maryland Geological Survey. Miocene Plates. [1904.]

—Maryland Geological Survey. Miocene Text. [1904.]

—ORTON, ED. Uses of Hydraulic Cements, Eno, 1904. [Geological Survey of Ohio, 4th series, Bulletin No. 2.]

—PERKINS, G. H. Report of the Vermont State Geologist, 1903–1904.

—PROSSER, CHAS. S., assisted by CUMINGS, EDGAR R. The Waverly Formations of Central Ohio. [From American Geologist, Vol. XXXIV, December, 1904.]

—REIS, HEINRICH, and KUMMEL, HENRY B., assisted by KNAPP, GEO. N. Clay Industry. [Geological Survey of New Jersey, Vol. VI.]

—RUSSELL, ISRAEL C. Co-operation among American Geographical Societies. (An address before the Section of Geology and Geography, American Association for the Advancement of science, Philadelphia meeting, December 27–31, 1904.) [Advanced pages from the Proceedings of the American Association for the Advancement of Science, Vol. LIV (1905).]

—SCHWARZ, E. H. Index to the Annual Reports of the Geological Commission, for the Years 1896–1903. [Cape Town, 1904.]

—VAN HISE, C. R. The Problems of Geology. [Reprinted from the Journal of Geology, Vol. XII (1904), No. 7.]

—Wisconsin Academy of Sciences, Arts and Letters, Transactions of the, Vol. XIV, Part II, 1903. [Madison, Wis., 1904.]

—West Australian Mining Industry. [Issued as a special edition of the Australian Mining Standard, December 8, 1904.]